Alternative Futures for the Department of Energy National Laboratories

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Figure 1. Department of Energy National Laboratories Under Consideration by the Task Force

White Papers on the Department of Energy Laboratories

I. Serving National Needs: An Overview of the DOE Laboratories

A. Introduction

The Department of Energy (DOE) manages the largest laboratory system of its kind in the world. With origins in the Manhattan Project, the DOE laboratories have evolved over the past 50 years to become a major component of the nation's infrastructure for maintaining U.S. leadership in scientific discovery and knowledge generation. Programs conducted at the Laboratories have consistently challenged our basic understanding of the world around us and driven new fields of scientific inquiry and technology development.

Contributions from the Laboratories in the future will help meet the National goals of environmental quality through clean energy sources and pollution-prevention technologies; enhanced security through continued reductions in the nuclear threat; continued leadership across the frontiers of scientific knowledge; and a growing economy fueled by technology innovations that open new markets, increase U.S. industrial competitiveness, and create high-skill, high-wage jobs for American workers.

The most valuable assets which the DOE Laboratories have brought to their mission assignments in the past -- and which will be dedicated to future missions -- are their human and physical resources. These assets are characterized by interdisciplinary teams with the skills to tackle national problems of great complexity and scope, and sophisticated and often unique scientific facilities that enable researchers to explore new scientific frontiers, to model and simulate processes and solutions to problems, and to achieve new understandings of how the world works and how technology can better address national needs. These resources have helped train generations of scientists and technologists who have carried the capabilities of the Laboratories to industry and academia.

Innovations and capabilities from the DOE Laboratories are behind innumerable technological achievements that have affected the nation's security, environmental quality, knowledge base, prosperity, and quality of life. Examples include:

- Development of the world's first nuclear explosive in a span of 28 months, from the date when the first scientists arrived at Los Alamos National Laboratory in 1942 until the first nuclear test in 1945. The scientists involved in this historic technological development are widely viewed to have been some of the most brilliant of the 20th Century. Their achievement required the collective efforts of physicists, chemists, mathematicians, metallurgists, engineers, and many other specialists -- a multi-disciplinary heritage which has been a hallmark of the Department of Energy laboratory system ever since.

- Development and continuous refinement of increasingly sophisticated computers. From the Univacs of the 1950's to the supercomputers of today, the Department's laboratories have been a test-bed for the first model of nearly every new top-end computer. Driven initially by defense and fusion applications, these systems now are employed at the laboratories for applications including global climate modeling; human genome research; designing next generation, fuel-efficient automobile engines; and modeling groundwater contamination.

- Technology breakthroughs in essentially all forms of energy sources and energy-efficiency technologies, including, for example, the original work on nuclear reactors; development of enhanced methodologies for oil and gas exploration; creation of new battery technologies for electric vehicles, new substrates for photovoltaic panels, and new energy-efficient window and building technologies; and advances in the development of fusion energy as a potential major future energy source.

- Original development of the field of medical isotope production and utilization. Laboratory research reactors currently are the sole source for californium-252, a radioisotope that has proven very effective in the treatment of certain cervical and brain cancers that are otherwise incurable. Other medical isotopes produced by Laboratory facilities are used for measuring bone loss in women (gadolinium-153), evaluation of coronary heart disease (potassium-43), treatment of prostate cancer (palladium-103), treatment of arthritis (tungsten/rhenium-188), and positron-emission tomography (germanium-68).

The scientists at the Department of Energy laboratories have served as invaluable consultants, experts, and hired researchers to the Government at-large throughout the past 50 years. For example, scientists of the DOE laboratories.

- Assisted the International Atomic Energy Agency with the physical inspections of Iraq's suspected nuclear and chemical weapons facilities.

- Provided a major advance to astronomical sciences with the design and prototype of the world's most powerful optical instrument, the Keck Telescope, which can peer 15 billion light years into space.

- Worked with the Department of Defense and United States intelligence agencies to determine possible sources of smuggled plutonium.

- Developed for the United States Army tank armor which achieved unheralded levels of survivability during the Persian Gulf war.

- Developed for the Department of Transportation a sophisticated computer model which can map commuter traffic to an unprecedented level of refinement, enabling new levels of transportation planning and air pollution studies.

- Developed for the United States Navy the nuclear reactors which have fueled U.S. ships and submarines for more than 100 million miles without an accident or a reactor failure.

These examples of laboratory activities illustrate the enormous variety of research underway within the confines of the Department of Energy laboratories. They also indicate the extent to which these laboratories truly are national assets -- serving national needs which extend far beyond the traditional mission boundaries of the Department of Energy. Although the Department of Energy laboratories had their origins in the Cold War, and their growth was fueled considerably by national security requirements, the resources of these facilities now are available for a much broader application to national needs. The existence of this national science and technology asset is one of the enduring legacies of the Cold War. Optimizing the utilization of these laboratories toward meeting the national security, energy, environmental, and economic needs of the future will be among the nation's major challenges -- and opportunities -- in the post Cold War world.

B. Who We Are

The Department of Energy laboratory system consists of 30 laboratories in 16 states, with combined budgets exceeding $6 billion and a scientific and technical staff which numbers close to 30,000. These facilities range from small, specialized laboratories with annual funding of less than $5 million per year, to large, diversified laboratories with annual operating budgets exceeding $1 billion. Nine of the major laboratories are “multi-program” laboratories, receiving funding from several different programs within the Department. Collectively, the laboratories are the major operational arm of the Department, performing much of the research and development which Congress directs the Department to perform through authorization and appropriations bills.

The Department of Energy Laboratories initially were established to direct the nation's efforts both in nuclear weapons and the peaceful use of nuclear energy, including nuclear power and later nuclear medicine. They also were given the mandate to support fundamental research in high energy and nuclear physics. In pursuing these objectives, the scientists and engineers at the National Laboratories explored scientific and technical boundaries across a range of disciplines, including materials science; advanced mathematical and computing techniques; frontier areas of physics, chemistry, health and environmental sciences, and geology; as well as newly emerging areas such as environmental impact assessments, systems analysis, and innovative engineering design. Today, the workforce of the National Laboratories displays a depth and breadth of scientific and technical competency found in very few institutions anywhere in the world.[1]

The Department of Energy Laboratories are government-owned, but are operated by private contractors selected from industry, academia, and university consortia. This

[1]See Section IV ”Core Technical Capabilities of the DOE Laboratories” for additional information on budgetary and workforce levels across the major technical competencies of the laboratories

government-owned, contractor-operated (GOCO) approach to laboratory management began in the 1940's to meet pressing wartime needs, and today provides flexibility in the assignment of resources and facilitates quick responses to a wide variety of program needs. This approach enables private sector and university-based R&D management experience to be brought to bear on government work. The GOCO system has offered significant advantages in attracting and retaining world-class scientists and achieving scientific excellence.

In recent years, the GOCO system has been the subject of significant concerns regarding administrative and business management issues.[2] At the same time, however, there has been a growing recognition that the GOCO approach utilized by the Department of Energy had resulted in generally superior technical performance than is found at government-owned, government-operated (GOGO) facilities.[3]

The quality of scientific performance demonstrated at the Department of Energy laboratories can be measured in many ways, including numbers of technical accomplishments; scientific awards and peer recognition; patents, licenses, and commercialized technologies; and satisfied customers. In each of these areas, the success of the DOE Laboratories has been strongly validated. For example:

- Since the inception of the DOE Laboratory System, 31 scientists associated with the Laboratories have won Nobel prizes; of that number, 18 performed research as Laboratory staff and 13 employed Laboratory facilities in their award-winning discoveries.

- The Department of Energy has received more "R&D 100" awards than any other institution. This award is given annually to technology innovations (both from the public and private sectors) which hold a strong prospect for commercial success. Approximately 500 licenses are awarded annually for technologies developed at the Laboratories.

- More private sector companies seeking opportunities for technology development and research assistance are referred each year by the independent National Technology Transfer Center to the Department of Energy Laboratories than to any other federal institution.

- The Department of Energy laboratories perform more work for other federal agencies than does any other government laboratory system. The high volume of

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[2] In response to such concerns, the Department in 1993 launched a major contract reform initiative aimed at preserving the attributes of GOCO management while addressing acknowledged deficiencies which had been experienced primarily at the Department's GOCO weapons production facilities.

[3] The Defense Science Board in 1987 proposed that some of the Department of Defense laboratories be converted from government-owned, government-operated (GOGO) labs to GOCOs. The Office of Technology Assessment and National Academy of Sciences also have made recommendations that the GOCO model be seriously considered for DOD's laboratories.

so-called "work for others" conducted by the Department of Energy laboratories -- nearly 20 percent of the entire funding which goes to the National Laboratories -- is a strong indication that the Department is successfully meeting the needs of other federal customers.

C. What We Do

The Department receives direction from Congress and the President to meet specific mission and programmatic objectives in areas ranging from alternative engine research to nuclear weapons dismantlement to nuclear waste clean-up to development of solar energy. Approximately 40 percent of the Department's overall $19 billion budget supports work performed at the Laboratories. The balance of the DOE budget supports researchers in academia, cost-shared research directly performed in industrial laboratories, the DOE weapons production/dismantlement complex, contractor support for environmental clean-up, the Energy Power Administration, and departmental operations.

Congress provides specific direction regarding how and where much of the Department's budget should be spent. In R&D areas, DOE program managers are responsible for establishing programs and determining where the best performance will be achieved for meeting programmatic goals in the Department's major mission areas of energy, basic science, national security, and environmental stewardship. Systematic planning and program reviews, including by independent advisory boards and peer review panels, serve as essential inputs for program development and funding decisions. Partnerships between the Laboratories and academic and industrial institutions are established as a means of helping meet the mutual goals of all parties. In addition, the Laboratories perform more than $1 billion in work for other government agencies.

1. Energy: Programs that Drive the Economy

The Department of Energy was formed, as a successor to the Atomic Energy Commission and the Energy Research and Development Administration, in response to the oil embargo and energy shortages of the 1970s. Contributing to the nation's energy security through creation of flexible, clean, efficient, and equitable energy supply and end-use technologies remains a major national challenge. U.S. consumers spend $450 billion annually on end-use energy commodities such as electricity, gasoline, and natural gas, and we spend $45 billion annually on imported oil. Although energy fuels growth, development, and improved standards of living, its use is one of the major contributors to the world's environmental problems, including urban air pollution, acid rain, and global climate change. As a result, environmentally-sound energy technologies such as renewables represent a major international need, one of the biggest emerging market opportunities worldwide, and thus a strong focus for the Department of Energy and its Laboratories.

The National Laboratories have contributed significantly to boosting energy efficiency performance of commercial and residential windows, lighting, and appliances; developing cleaner-burning fossil-fuel technologies; developing nuclear reactors and enhanced nuclear reactor safety; improving efficiency and reducing CFC emissions from air conditioning and refrigeration systems; heightening the efficiency and effectiveness of oil drilling and recovery operations; and reducing the energy necessary to make important industrial chemicals. Together, these advances are resulting in billions of dollars worth of energy savings annually. (see box) The DOE laboratories conduct about $800 million of energy technology R&D annually.

Energy Efficiency R&D Has Saved Billions

Since the mid-1970's, a cumulative $70 million investment by the Department of Energy in energy efficiency programs at Lawrence Berkeley Laboratory has helped to spawn a $2.5-billion annual U.S. market for four particular technologies and services: high efficiency windows, high-frequency fluorescent lamp ballasts; residential equipment efficiency standards; and computer tools for energy-efficient building design. As of 1993, this R&D investment has resulted in $6 billion in energy savings, an amount that will grow to $20 billion over their entire service life (with net return on investment for consumers of $10 billion). The advances in window technology drew upon a wide variety of Laboratory strengths as teams of research architects and thin film material scientists worked with physicists and engineers with an understanding of solar and indoor radiation, the reflective and adsorptive properties of materials, and the technology for manipulating these materials for enhanced performance.

2. Basic Research: World Leadership for Science, Mathematics and Engineering

The Department of Energy Laboratories have a rich science and technology base and a tradition of pursuing knowledge at the absolute frontiers of science. As a result, many major scientific accomplishments, from the subatomic to the cosmic scale, trace their roots to research conducted at the DOE National Laboratories. Large and unique world-class research facilities have enabled scientists to probe the fundamental building blocks of nature, decipher the forces of molecular biology, survey the surfaces of all forms of materials, and explore developments of the universe tracking back to the Big Bang.

Through the development and operation of particle accelerators for high-energy physics, the Laboratories have pioneered the development of powerful synchrotron radiation sources[4] for materials, chemical, and life sciences research. These facilities host large research programs involving thousands of academic, industrial, and government investigators. Research interests range from mapping the structure of materials' surfaces to visualizing the interior surfaces of arteries.

The Laboratories also operate facilities that utilize powerful beams of neutrons for studying materials such as the liquid crystals used in portable computer displays, metals and semiconductors used in electronics, industrial polymers, structural studies of biomolecules, and high-temperature superconductors. Virtually everything now known about certain vital characteristics of materials that are strong candidates for superconductivity comes from neutron scattering studies performed at the DOE Laboratories. These materials may revolutionize transportation and telecommunications.

Scientific inquiry at the Laboratories has proceeded along pathways that have resulted in developments that could never have been anticipated. Radioisotope separation science in the 1940s, for example, sparked the field of nuclear medicine, which today affects the lives of millions of people annually through cancer treatment and other radioisotope examination and treatment procedures. Studies into the causes and effects of radiation damage in reactor materials led to toughened structural ceramics for advanced diesel engines and gas turbines. And the combination of sophisticated computational capabilities and research in molecular biology at the Laboratories resulted in the development of the Human Genome program. This program has now grown into an international effort to map and sequence the entire human genome, which comprises three billion DNA base pairs. Deciphering the human genome, literally the blueprint for life, will provide unparalleled insight into the molecular basis of the thousands of genetic disorders that afflict humans -- providing the foundations for innovative medical diagnostics, genetic counseling, and ultimate mitigation of these disorders.

DOE laboratories have been instrumental in advancing entire fields of scientific research, including high energy and nuclear physics, plasma physics, nuclear medicine, nuclear engineering, supercomputing, and global climate research. Other examples include systems ecology founded on energy and nutrient studies using radiotracers, bioenergetics to trace the pathways of plant photosynthesis, and animal metabolism

[4] Synchrotron light sources utilize powerful beams of x-rays and ultraviolet radiation for conducting state-of-the-art structural studies. Synchrotron radiation initially was derived as a by-product of electron accelerators built for physics research. The results showed such high promise that later accelerators were built expressly to produce synchrotron radiation for materials research.

using related radiotracer techniques. The Department of Energy Laboratories perform approximately $3 billion in basic and applied R&D annually.

3. National Security: Reducing Nuclear Danger

National Security R&D in the Department of Energy is dedicated primarily to nuclear weapon activities, including:

- Science-based stewardship of the nuclear weapons stockpile;
- Support of nuclear weapon dismantlement and drawdown of U.S. and former Soviet stockpiles to their negotiated START II levels; and
- Development of technologies to help discourage and prevent the proliferation of weapons of mass destruction.

The nuclear weapons R&D program provides the science and technology infrastructure, including technical expertise and facilities, required to support a broad spectrum of DOE Defense Programs activities, which include design, engineering, prototyping, testing, and evaluation of nuclear weapons; supstockpile management; weapons dismantlement; arms control; and nonproliferation. Stockpile stewardship involves quality assessment and engineering, stockpile surveillance, and an independent nuclear safety assessment function.

Major thrusts in the nuclear weapons R&D program include: developing advanced predictive capabilities and above-ground experimentation facilities in light of the existing nuclear weapons test ban and developing advanced manufacturing technologies to provide a smaller and more efficient weapons production complex in response to decreasing defense budgets. These activities all rely upon the weapons R&D base, including a sustained competency in nuclear weapon design, for their successful accomplishment.

The three multiprogram defense laboratories work closely with DOE's production complex to design safe and efficient dismantlement processes. Automated processes using robotics and computer modeling are being developed by the laboratories to safely and cost-effectively handle the dismantlement of up to 2,000 weapons per year.

Assisting Russia and other former Soviet republics in reducing the size of their nuclear weapon stockpile is an important part of this activity. The laboratories are involved in several agreements with Russia for collaboration on the safety, security, and dismantlement of nuclear weapons of the former Soviet Union, and also assisting Russia in planning for the disposition of nuclear weapons-grade materials. Reducing the threat of nuclear weapon proliferation requires competence in nuclear technology and comprehensive and effective cognizance of international weapons developments.

The National Laboratories conduct some of the nation's premier research, development, and analysis for intelligence, proliferation detection, arms control, and verification technology. The Laboratories have developed instrumentation to verify compliance with the Limited Test Ban Treaty, the Nuclear Nonproliferation Treaty, the Intermediate Nuclear Forces Treaty, and the Strategic Arms Reduction Treaties (START). The Laboratories perform more than $2 billion in national security research and technology development directly for the Department of Energy, as well as nearly $1 billion in additional defense-related work for the Department of Defense.

4. Environment: Stewardship and Prevention of Waste

DOE is committed to cleaning up the environmental legacy of its past activities (mainly from the nuclear weapons program), preventing or minimizing new waste production, and assisting in the development of energy-efficient pollution prevention technologies for transportation and industrial applications.

Most of the actual cleanup work of environmental waste sites associated with the nuclear weapons production complex is conducted by private contractors, but the National Laboratories are actively involved in the technology development work necessary to help drive down the future costs of radioactive and chemical waste clean-up. Successes include radioactive waste isolation techniques, waste-shipment standards, and the use of genetically engineered organisms that consume waste or that emit light to show researchers when, where, and at what rate waste is being consumed.

Over the years, the labs have expanded their focus on waste clean-up and prevention to include broader environmental issues, such as nutrient cycling through various ecosystems, assessment of the acid-rain cycle, and examination of the effects of different types of power plants on the environment. The laboratories have worked on a range of technologies and manufacturing processes aimed at reducing or eliminating pollutants. Major accomplishments have been made in developing environmentally conscious manufacturing techniques for semiconductor manufacturing, including the development of a technique which enables companies to completely eliminate of the use of CFCs during semiconductor manufacturing. This development alone is expected to eliminate approximately 18,000 tons per year of CFC usage by the year 2010 and decrease energy use by 1.8 trillion Btu per year by the year 2010. The further development of technologies that integrate energy, environment, and economic considerations with the goal of contributing to sustainable economic development is a growing focus for laboratory activities. The Laboratories perform about $1.2 billion in environmental research and technology development annually.

5. Technology Partnerships: Enhancing National Competitiveness

During the past five years, spurred in large part by Congressional legislation adopted during the 1980s which promotes technology transfer[5], the National Laboratories have

[5] The 1980 Stevenson-Wydler Act required the Department of Energy to establish technology transfer as an explicit mission of its laboratories. Subsequent amendments to that act, in the form of the 1986 Federal Technology Transfer Act and the 1989 National Competitiveness Technology Transfer Act, gave the

made considerable progress in teaming with industry in technology partnerships. During this period there has been a considerable evolution in thought about the role of the National Laboratories in contributing to economic competitiveness. Ten years ago, many in industry viewed the National Laboratories as “technology warehouses” that contained uncommercialized commodities ripe for transfer. Others saw the Laboratories as institutions that were inaccessible or had little to offer. These views often resulted in false expectations, disappointments, or missed opportunities.

Over the past several years, however, technology transfer has come to be characterized by a sophisticated set of partnerships between the Laboratories and industry, with clearly defined expectations and mutually-crafted R&D agendas. These partnerships have been growing at an unprecedented pace, with more than 1000 cooperative research and development agreements established between industry and the Laboratories during the past four years.

Through these partnerships, the Laboratories have begun to earn industry’s trust, confidence, and support, and the Laboratories are acquiring new insight into the challenges faced by industry in technology maturation, product development, and manufacturability. As the next section describes, technology partnerships are not so much a mission area of the Laboratories, as they are a mode of operation. Increasingly, throughout the Laboratory system, partnerships with industry; academia; and state, local and other federal government agencies are the means of best meeting the research objectives established for the Laboratories. Through such partnerships, the expertise and resources of the Laboratories are teamed with those of other complementary institutions in a fashion that can shorten the time between basic scientific discoveries and product developments, and -- in the process -- strengthen the Nation's leadership position in economic growth, scientific advance, and technological innovation.

6. Science and Engineering Education and Training

The Laboratories offer a compelling environment and opportunity for helping educate and train students in science and engineering. Tens of thousands of students frequent the Laboratories annually for "hands-on" experiences that complement classroom education and contribute to the Nation's future supply of skilled scientists and technicians. The Laboratories sponsor post-doctoral fellowships and other research fellowships for hundreds of top-ranked graduate students annually, and many Laboratory personnel hold joint appointments at universities -- where they bring to their profession as educators the experiences drawn from their profession as government researchers. Through programs at all of the Laboratories, these National scientific assets are being put to use to assist in the education and training of students at the frontiers of science and technology. These facilities also have been used to help train

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Department and its Laboratories and facilities additional authority and mechanisms for working cooperatively with industry.

thousands of teachers in the best techniques for presenting science and technology in the classroom.

D. How We Do It

If there is one word that best describes how the Department of Energy laboratories execute their mission assignments, it is integration -- of scientists and engineers into multi-disciplinary teams; of basic science, applied science, and technology development into a holistic approach to problem-solving; and of complementary skills and perspectives from the federal government, academia, and the private sector to the mutual benefit of all parties. And if there is a single explanation for the ability of the laboratories to achieve such integration, it lies in the breadth and depth of core technical capabilities which form the set of skills which the laboratories exercise in pursuit of their mission assignments.

a) Scientific Facilities and Multi-disciplinary Workforce

By virtue of several decades of investment by the Nation in the Department of Energy laboratories, these institutions currently exhibit a combination of physical and human R&D assets not duplicated anywhere in the world. The replacement value of the physical R&D assets at these laboratories exceeds $30 billion, and includes facilities such as:

- One of the world's premier assemblages of high-performance computing centers, including many of the world's most powerful scientific computers, which serve as a fundamental tool for helping meet essentially all of the missions of the laboratories and which are setting the stage for broad utilization of massively-parallel computers in the future;

- The world's largest laser system, which is being utilized to simulate conditions within nuclear weapons, to advance our understanding of the universe, and to explore options for creating fusion energy;

- Two of the world's most powerful particle accelerators, which are being used to discern the fundamental building blocks of nature;

- Three of the nation's most sophisticated facilities for mapping the human genome;

- Three of the world’s most powerful neutron sources (two reactors and one accelerator), which provide the means for materials characterization and medical isotope production, and environmental analysis;

- One of the world's leading tokamak reactors for studying fusion plasmas, which has produced the most power ever in controlled fusion energy experiments;

- Three of the world's premier X-ray radiation sources, which are being tapped for materials research in areas ranging from structural biology to designing integrated circuits to developing new industrial chemicals; and

- Major and unique facilities for studying combustion, solar thermal generation of electricity, photovoltaic cells, energy efficient lighting and window systems, nuclear reactor safety, energy utilization for construction materials and building technologies, and semiconductor reliability.

These are but a few examples of the research assets housed within the Department of Energy laboratories. Yet, even a partial listing such as this speaks volumes about the capacity of these labs to probe new frontiers of science, to work with industry in new areas of technology development, and to deliver scientific and technological progress in meeting important national needs. The full inventory of the major R&D assets at these labs would comprise a very long list, but in-and-of-itself would not paint a full picture of the means by which the Department and its laboratories execute their missions. This is because the facilities themselves are of little value without the trained workforce which, in many cases, designed and built the facilities, and which now operates them in the pursuit of scientific and technological advance.

The Department of Energy laboratories support an extraordinarily broad collection of scientists and engineers, with established -- and in many cases world-class -- expertise in areas including physics, chemistry, mathematics, computer science, engineering, materials science, biology, earth sciences, environmental science, metallurgy, and systems engineering. No other federal laboratory system has the ingredients of such a multi-disciplinary environment as exists within the Department of Energy laboratories, which is one of the reasons why these labs represent such a distinctive national asset.

b) Core Technical Capabilities

The facilities and trained workforce of the Laboratories can be presented in the context of eight major core technical capabilities, which together represent generic areas of expertise which enable the Laboratories to address their missions. These core technical capabilities are:

- Advanced Materials, Synthesis and Characterization
- Advanced Computing, Modeling and Simulation
- Advanced Manufacturing and Processes Technology
- Bioscience and Biotechnology
- Nuclear Science and Technology, High Energy and Nuclear Physics
- Advanced Energy Technologies and End Use Applications
- Environmental Science and Remediation Technology
- Integrated Defense Science and Technology

In addition to these major areas of expertise which are characteristic of the entire Laboratory system, individual laboratories within the system also have important and unique core capabilities, such as in laser and electro-optics, sensors and instrumentation, electronics, and neutron-based science. These additional strengths supplement the total resource represented by the Laboratory system. Each of these core capabilities depends upon multi-disciplinary skills drawn from the workforce of the Laboratories. Collectively, these capabilities provide the means by which the Laboratories solve complex problems assigned by the Department; respond to new challenges and requests for assistance from other government agencies, academia, and the private sector; and generally move ideas from concept to reality -- either through the generation of experimental results or development of new technologies and operational systems.

c) Integrated Approaches to Problem Solving

The combination of a pervasive problem-solving culture at the Laboratories, and the broad and diverse technical skills and core capabilities resident within the Laboratories, provide the ability for these institutions to address national issues in an integrated fashion -- through multi-disciplinary teams; through integration of basic science, applied science, and technology development; and through collaborative efforts with researchers from academia, industry, and other government agencies.

The Laboratories are at their best in bringing teams together to address large, complex problems. Because the Laboratories are organized to solve problems in a fashion that is unconstrained by the boundaries of traditional academic disciplines, they have a multi-disciplinary operational approach that is distinctive from the single-discipline methodology which remains generally characteristic of academia. In addition, because many of the problems assigned to the Laboratories are of a high-risk, long-term nature, the Laboratories generally have a different orientation than found in industrial laboratories, where near-term market forces are of paramount consideration. Yet, the Laboratories, because of their unique human and physical assets, have served as a catalyst for developing teams of government, academic, and industrial researchers. In this fashion, complementary strengths of researchers from varying perspectives are brought to bear on problems of common interest. Examples of integrated approaches to problem solving include:

- ***National Oil Technology Partnership:*** This effort involves all nine multi-program laboratories in partnership with the petroleum industry. Nineteen projects currently are underway in such diverse areas as seismic fracture detection, synthetic diamond drill bit development, and failure analysis of extraction devices. This partnership spawned an entirely new market in diamond drill bits and has yielded tens of millions of dollars in savings to petroleum companies.

- ***The American Textiles (AMTEX) Partnership:*** This effort involves ten of the Departmental Laboratories and a consortium of five nonprofit research, education, and technology transfer institutions representing the vertically-integrated American textile industry. The projects involve Laboratory strengths in advanced materials and processes, energy efficiency, waste minimization, information systems, and automation, in an effort to improve the competitiveness of the U.S. textile industry, from fiber through finished product.

- ***The U.S. Advanced Battery Consortium (USABC):*** This effort links the Department of Energy Laboratories, the "Big Three" automobile manufacturers, and the utility-supported Electric Power Research Institute, for the purpose of developing advanced batteries for electric vehicles that will both perform like present internal-combustion engine vehicles and satisfy various state mandates for zero-emission vehicles. This cost-shared partnership takes advantage of Laboratory strengths in advanced materials, energy systems, manufacturing, and diagnostics.[6]

- ***National Center for Advanced Information Components Manufacturing:*** This partnership involves the Advanced Research Projects Agency of the Department of Defense, the Department of Energy, and industry in the development of advanced electronics technologies, such as flat-panel displays. The effort draws on Laboratory strengths in manufacturing, computation and simulation, and electronics. Funding for the Center is provided by ARPA and supports research teams from the Laboratories, industry and academia.

- ***The PHENIX Detector:*** This large, nuclear physics detector will serve as a central data-gathering instrument for a major new particle accelerator at the Brookhaven National Laboratory. Construction of the detector involves approximately 360 scientists and engineers located at five Department of Energy Laboratories, 15 U.S. universities, and 21 foreign institutions and universities. This detector will examine nuclear matter which will be at some of the most extreme conditions of temperature and density ever achieved in a laboratory -- conditions that probably have not existed in the universe since the Big Bang. Construction of PHENIX draws on Laboratory strengths in nuclear physics; the design, development, and construction of large-scale research facilities; systems engineering; sensors and instrumentation; and advanced computation, modeling, and simulation.

- ***Superconductivity Partnership Initiative:*** This joint Department of Energy-industry effort, involving research centers at three of the Laboratories, has helped pioneer the fabrication and application of new high-temperature superconducting materials. Such materials, which conduct electricity with minimal resistance, hold the potential for widespread applications in areas ranging from appliances and electronic devices to medical imaging to power transmission and magnetic energy storage. Drawing on Laboratory expertise in advanced materials and processing, energy systems, advanced computing, and condensed matter physics, the centers are playing an important role in keeping U.S. industry competitive in the global race to develop superconductivity technology.

[6] The Laboratories also are major players, in collaboration with the “Big Three” auto manufacturers and other agencies, in the Partnership for New Generation Vehicles, an R&D effort aimed at developing a new generation of vehicles that will be three times more energy-efficient than today’s cars.

- ***Atmospheric Radiation Measurement Program:*** This DOE Program integrates the resources of eight DOE labs, 13 other federal laboratories, more than 20 leading research universities, and foreign and private enterprises to address critical elements of the United States Global Change Research Program. Research focuses on atmospheric radiative processes and the role of clouds, which are among the most critical needs for the improvement of climate prediction models identified by the National program. This major collaboration is resulting in a new understanding of basic climate processes and of the effects of climate on ecosystems and the evolution of natural weather systems.

These examples provide a snapshot of how the Laboratories approach problem solving through a distinguishing integration of skills, capabilities, technologies, facilities, and research performers -- including partners from throughout the Laboratory system, other federal agencies, industry, academia, and around the world. The extent of coordination, integration, and engagement between the Department of Energy Laboratories and other research performers also is illustrated by the following statistics:

- During 1993, the 60 major research and user facilities operated at the Department of Energy Laboratories were utilized by more than 9,700 scientists and engineers, representing 188 U.S. colleges and universities, 103 U.S companies, and 26 U.S. laboratories.

- During 1993, more than 20,000 scientists and engineers from industry, academia, and other government agencies worked as guest researchers at the nine multi-program National Laboratories.

- During 1993, the nine multi-program National Laboratories received more than 170,000 visitors, who frequented the laboratories for purposes such as briefings, technical discussions, and meetings.

- During 1992, the Department of Energy Laboratories had formal technology transfer partnership arrangements with more than 3,400 companies and academic institutions.[7]

- During the past four years, the Department of Energy Laboratories have entered into more than 1,000 Cooperative Research and Development Agreements (CRADAs) with more than 700 companies; the combined cost-shared value of these cooperative R&D programs exceeds $1.9 billion.

From fundamental and applied research, through design and development of applications, to process engineering and manufacturing support, the laboratories are an environment where all aspects of technology development and deployment are routinely addressed. The ability to integrate across the suite of capabilities at the laboratories

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[7] These arrangements included cost-shared contracts, cooperative research and development agreements, R&D consortia, personnel exchange programs, licensing agreements, user facility agreements, and consulting agreements.

explains why these institutions have become magnets for such a large number of academic and industrial researchers.

E. Looking to the Future in a Changing World

The nation faces major new challenges as a result of the end of the Cold War, growing concerns about U.S. economic competitiveness, the need to achieve sustainable economic growth and environmental quality, and the reality of stringent federal budgets. As a result of these forces, the national scientific and technological enterprise is experiencing perhaps its most significant transformation since the end of World War II. Industry increasingly is looking for opportunities to team with other R&D performers -- including former competitors -- in the development of new technologies; there is growing political pressure for all public investments to be tied more closely to national needs; the principles of total quality management increasingly are being applied throughout industry, including at research institutions; and the traditional boundaries between federal R&D agencies are giving way as the Nation seeks to provide multi-agency, coordinated approaches to satisfying National needs.[8]

Faced with these new circumstances, the Department of Energy Laboratories are changing dramatically. The defense programs at the Laboratories are undergoing a complete transformation. Partnerships between the Laboratories and industry are growing at an unprecedented pace, far exceeding available funding. The Department has instituted new contract reform measures aimed at improving management of the Laboratories. In addition, the Laboratories are working more closely together as a system than at any time in the past and are forging strong new relationships with other government agencies. These changes all suggest a general direction for the future of the Laboratories. Although the precise research agenda will emerge and evolve with time, the focus for the Laboratories in the future will be on helping meet major National needs for which science and technology play a role. The challenges include:

- ***Providing Energy Resources:*** Global population growth and expected increases in energy utilization, particularly in developing nations, create both challenges to the environment and opportunities for the provision of clean energy sources to world markets. The potential risks of global climate change will demand continued technical advances in areas such as sustainable energy technologies; efficiency improvements for fossil fuel combustion; and energy-efficient materials, manufacturing processes, and transportation systems. The development of fusion energy, hydrogen energy, and options for advanced nuclear power all must be explored as part of a National program to provide secure, reliable, and diverse energy for the future.

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[8] The President's Science Advisor has referred to the establishment of a "virtual R&D agency," which involves utilization of the full spectrum of federal R&D capabilities in an integrated and coordinated fashion, facilitated by the National Science and Technology Council.

- ***Reducing the Nuclear Danger:*** The end of the Cold War has provided an historic opportunity to reduce global nuclear weapons stockpiles, yet the nuclear danger persists due to nuclear proliferation, potential terrorist actions, and significant quantities of weapons-grade materials and the know-how to build nuclear devices. The United States will continue to rely upon nuclear weapons for deterrence for the foreseeable future, yet these weapons must be kept reliable, safe, and secure without nuclear testing. Meeting this goal will require highly sophisticated computational modeling and simulation, as well as above-ground experimentation. The Nation will continue to need a nuclear weapons production and dismantlement complex, yet one that is substantially smaller, more efficient, and less costly than exists today.

- ***Environmental Stewardship:*** The President recently stated that "Attaining sustainable development is one of the greatest challenges facing our country and the global community -- a challenge that can only be met by developing and deploying technologies that will protect the environment while sustaining economic growth."[9] Such technologies will be required for enhanced clean-up of existing environmental problems, such as the nuclear waste legacy of the weapons production complex, as well as for designing new industrial processes, manufacturing techniques, and modes of economic activity that are resource efficient and environmentally benign.

- ***Maintaining Leadership in Science and Technology:*** The Nation has reaped enormous benefits from its investments in science and technology over the past 50 years, yet continued scientific advance -- the fuel for technology's engine -- will be essential to help solve problems such as protecting the environment, improving human health, ensuring national security, and providing continued economic prosperity. Continued exploration of scientific frontiers contributes to the nation's knowledge base and capacity for innovative solutions to emerging problems and National needs.

- ***Technology Partnerships:*** Among the nation's greatest challenges for the future will be to strengthen and expand public-private partnerships aimed at technology development and enhanced U.S. industrial competitiveness. This challenge requires broad engagement among industry, federal and state governments, and academia in the development of shared visions and coordinated management strategies for accelerating innovation and technology development.

The economic, environmental, national security, and scientific challenges of the 21st Century will require collective national responses which take advantage of disparate yet complementary strengths throughout society. The Department of Energy Laboratories represent one of the major national assets available to help address emerging National needs. The Laboratories are well suited to address such challenges, precisely because of the diversity and depth of their technical capabilities. The Laboratory system has served as a versatile and valuable resource to the nation in the past, with a record of

[9] Technology for a Sustainable Future: A Framework for Action, The White House, July 1994, p 1.

accomplishments that have expanded our understanding of the world, created new fields of science and technology, established new commercial markets, and, in the case of national security contributions, determined the course of history.

In the future, after completing their most substantive change in operating method in decades, the DOE Laboratories will be important players -- teamed with industry, academia, and other government agencies -- in the Nation's concerted effort to provide a sustainable society which provides security, intellectual renewal, and prosperity for future generations. In looking forward during a time of change, the Department of Energy and its Laboratories endorse and embrace the guidance of the President:

> "***The challenges we face -- from our competitors abroad and from our people at home -- demand dramatic innovation and bold action that will not just revive our economy now but also ensure our economic growth well into the future. Building America's economic strength through technology demands new initiatives that confront these challenges effectively, efficiently, and creatively."***
>
> ***President William J. Clinton***
> **Technology for America's Growth,**
> **A New Direction to Build Economic Strength**

II. DOE Lab Contributions to the Nation's Scientific Enterprise

A. Introduction

On August 3, 1994, the Clinton Administration announced a new National science policy aimed at maintaining world leadership in basic science, mathematics and engineering. Titled Science in the National Interest, the policy document ranks among the most significant Presidential statements on the importance of fundamental science in the past fifty years. The Nation's investment in research and development is heralded for having produced "a scientific enterprise without peer," and our scientific strength is characterized as "a treasure which we must sustain and build on for the future."

The treasure which comprises our scientific establishment involves public and private institutions, researchers, facilities and instrumentation located throughout the Nation. The myriad laboratories and individuals -- and the American public which has provided them with federal public support -- all have reason to celebrate the historic accomplishments which our scientific enterprise has provided, at an accelerating pace, particularly since the end of World War II. We all must also confront the challenges of the future as we seek to sustain U.S. scientific excellence and work to strengthen the role of science in serving core National needs in areas such as improved health care, environmental protection, economic competitiveness, and national security.

In developing a new National science investment strategy, Science in the National Interest states that "we must reexamine every element of the enterprise" to ensure that each element is as strong as it can be given limited resources. The fundamental science portfolio of the Department of Energy (DOE), and particularly of its laboratories, represents one of the nation's major scientific assets, and appropriately should be reexamined as the Nation addresses the challenges and opportunities of a post-Cold War world.

This paper reviews the role of science and technology at the Department of Energy's laboratories and discusses the Department's contributions of the DOE laboratory system to the Nation's research infrastructure. The National goals delineated in Science in the National Interest are used as the structure for describing the contributions of the DOE laboratory system[10] in the past, and for providing recommendations aimed at achieving continued scientific excellence in the future.

[10] The Department of Energy laboratory system includes nine multi-program, National laboratories;11 smaller, single-program laboratories; and 10 highly-focussed mission-specific laboratories.

B. Science and Technology at the Department of Energy

1. A Tradition of Scientific Exploration

The Department of Energy Laboratories have a rich science and technology base and a tradition of pursuing knowledge at the frontiers of science. As a result, many major scientific accomplishments have emerged from research conducted at the DOE Laboratories. These range from conducting pioneering work on the fundamental structure of matter to expanding our understanding of the global environment to developing technologies to map the human genome.

The construction and operation of large-scale, basic research user facilities has been one of the distinguishing characteristics of the Department of Energy. The origins of this mode of research date back to the invention of the cyclotron in 1929 by Ernest O. Lawrence in Berkeley, California. In 1931, Lawrence established what then was called the Radiation Laboratory to tackle large-scale science in an intentional and intensely multi-disciplinary fashion. To help achieve this purpose, Lawrence built a large cyclotron which was of a scale and character unlike anything that could be built or sustained within an academic setting. His laboratory was the genesis of the present Lawrence Berkeley Laboratory. The cyclotron project set the stage for the development and operation of a series of major research and user facilities which have been signature contributions by the Department's laboratories to the Nation for the past 60 years. Lawrence's work also established the multi-disciplinary approach to problem solving which has been a hallmark of the research environment at the DOE Laboratories ever since.

Among the major research facilities at the Laboratories are major particle accelerators which have effectively defined the fields of high energy and nuclear physics over the past 50 years. Through the construction and operation of a series of powerful particle accelerators, the Laboratories have discovered many of nature's most fundamental particles and revealed the forces which govern their interactions. Recent evidence of the "top quark," the sixth of nature's basic building blocks, through research at DOE's Fermi National Accelerator Laboratory exemplifies such work -- which has helped create the foundation of knowledge that underpins other fields of science.

In the 1950s, the Laboratories developed the means of utilizing a by-product of accelerator operations -- synchrotron radiation -- for exploring new frontiers in materials, chemical, and life science research. The Department's synchrotron radiation facilities (commonly referred to as "light sources") generate powerful beams of ultraviolet light and x-rays for studying materials at the molecular level. These light sources have become indispensable tools for research in areas as diverse as studying materials for integrated circuits, mapping the structure of industrial chemicals, and designing molecules for future use in pharmaceuticals. The Laboratories also have built and operated facilities which generate powerful sources of neutrons. Because neutrons are uncharged, they can penetrate deeply into sample materials and give precise information on the positions and motions of individual atoms. The neutron research facilities of the Laboratories have provided major advances in our understanding of materials such as superconducting materials, polymers, and liquid crystals used in portable computer displays. These facilities also are a source of radioisotopes for medical, research, and industrial applications. In fact, the field of nuclear medicine and the medical use of radioisotopes trace their origins to work at the DOE Laboratories.

The Department currently operates more than 60 major research and user facilities that provide access to scientific frontiers that would not otherwise be reached for materials, medical, chemical, biological, and pharmacological research. More than 9700 scientists and engineers utilized these major facilities in 1993, representing more than a 50 percent increase over the past six years (Figure 2). Researchers using these facilities represented 278 U.S. colleges and universities, 265 U.S. companies, and 47 U.S. laboratories (Figure 3). The thousands of researchers who conduct their work at these facilities often do so in collaborative teams that combine the complementary strengths and perspectives from industry, academia and the federal government . The resultant contributions of these research performers are measured in the scores of scientific papers, proceedings, patents, and commercial products that emanate from their supporting institutions.

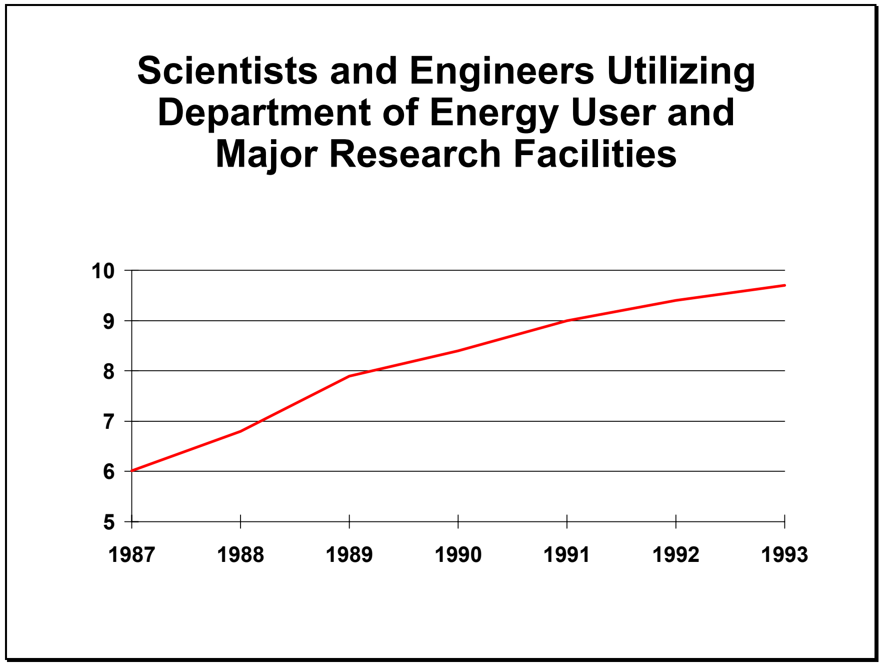

Figure 2. Utilization of Major Research Facilities

The major research and user facilities of the Department's Laboratories exist in synergy with an in-house research staff that complements, but is not necessarily dependent upon, such facilities. For example, small teams of principle investigators at the Laboratories have provided major contributions in areas such as atmospheric chemistry, microbiology, catalysis, and even cosmology. If there is one ubiquitous tool within the Laboratory system, however, it is high performance computers. From the earliest days of computers to the present, the Laboratories have been among the world's leading experts in computational science, modeling, and simulation. Initially driven by the data management requirements of national security, fusion energy, and high energy physics applications, these systems now are fully engaged by the Laboratories in National challenges including global climate modeling, designing fuel-efficient automobiles, and human genome research.

2. Science is Central to the Department's Missions

The examples listed above provide but a few illustrations of scientific and technological accomplishments of the Department and its Laboratories. However, these examples, in-and-of- themselves, do little to convey the cardinal importance of science and technology to the overall success of the Department in meeting its assigned missions. It is no understatement to say that science and technology are the most important means through which a majority of the Department's activities are conducted. This reality is made clear in the Department's May 1994 strategic plan, Fueling a Competitive Economy, which positions science and technology at the center of the Department's five major business lines -- intersecting and amplifying each mission (Figure 4).

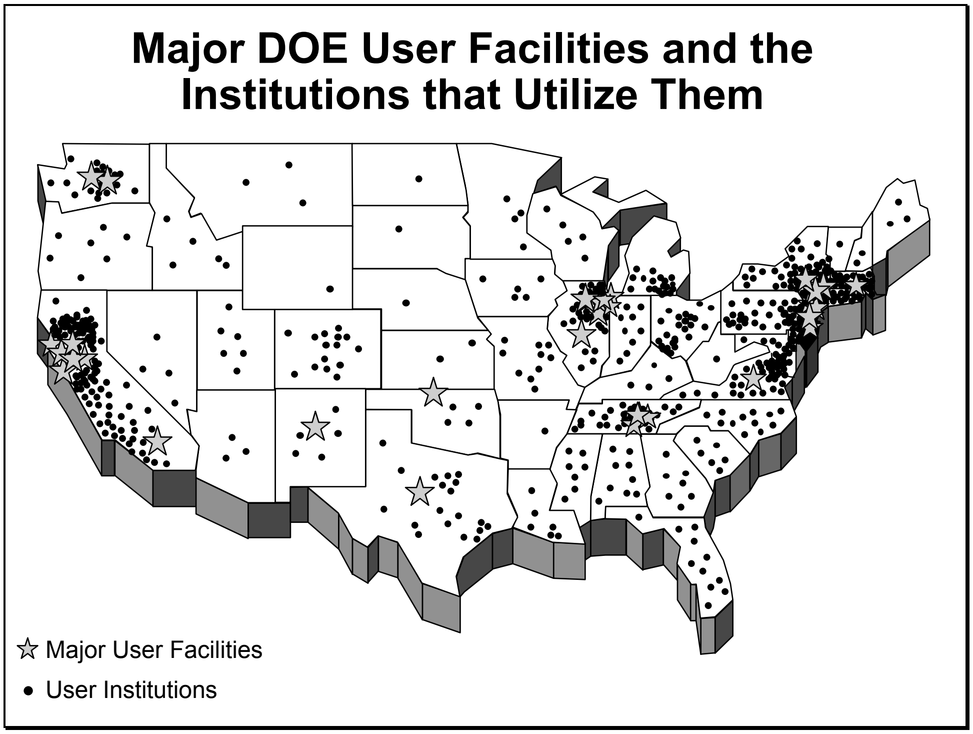

Figure 3. Institutions Using Research Facilities

3. Program Scope and Execution

The Department's total science and technology investment for Fiscal Year 1994 was $7.3 billion,[11] amounting to approximately 40 percent of the Department's overall Fiscal Year 1994 budget of $19 billion, and 10 percent of the total federal R&D budget of $74 billion.[12] The Department’s $3.4 billion funding of basic and applied research (excluding technology development, equipment, and construction) is fourth among the 16 agencies that are the primary Federal supporters of science and technology. This level follows the National

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[11] Includes research, development, capital equipment and construction of research facilities.

[12] This figure includes R&D and R&D plant operations; source: Science & Engineering Indicators-1993, National Science Foundation, National Science Board.

Institutes of Health at $8.9 billion, the Department of Defense at $4.3 billion, and the National Aeronautics and Space Administration at $4.1 billion. The Department of Energy supports the largest federal program in materials research and funds 90 percent of the nation's research in high energy physics.

The Department executes its science and technology function in many ways, including through grants to university researchers, cost-shared research programs with industry, construction and operation of major scientific user facilities, and laboratory-based research programs. For example, the Department's research program supports approximately 1800 university R&D grants totaling more than $600 million annually at more than 100 U.S. universities.

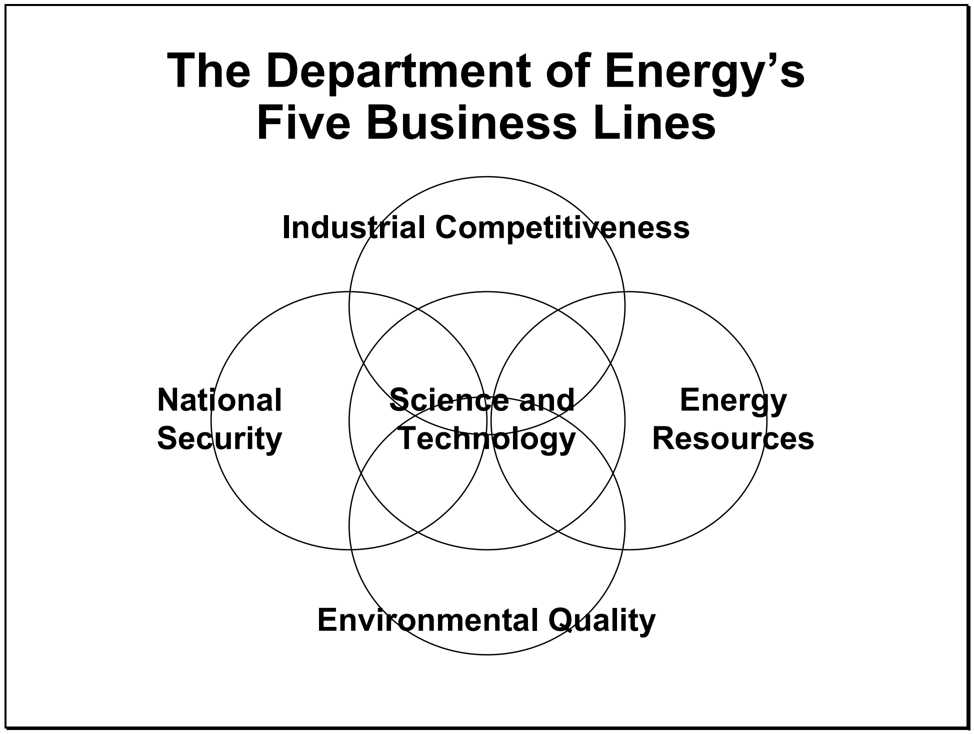

Figure 4. DOE Business Lines

The organization and management of the Department's research programs is the primary responsibility of the Department's program managers, who develop and manage research programs in response to legislative and Executive Branch direction. These programs are executed through research performed across a range of R&D performers, sometimes including multiple universities, companies, and DOE laboratories. Through peer evaluation and program reviews, the Departmental program managers ensure that the individual tasks among distributed researchers are integrated and are contributing toward the overall research objectives of the program.

C. DOE Contributions to National Science Policy Goals

The basic and applied research programs of the Department and its laboratories fit well and fully within the goals that are stated in the August 1994 National science policy document, Science in the National Interest. This section describes current activities and past accomplishments for each of the goals delineated in the White House science policy.[13] Recommendations are also included that have been developed by the Department as a means of helping achieve these National goals.

1. Goal: Maintain Leadership Across the Frontiers of Scientific Knowledge

Through its laboratory programs, including through its major research and user facilities, the Department is engaged in scientific exploration that spans from the fundamental building blocks of matter to the far reaches of the Universe to practical applications of physical and biological science.

Research conducted at Department of Energy laboratories has excelled within its disciplines, and also has helped create entirely new fields of scientific inquiry. For example, the Human Genome Program was conceived and initiated by the Department of Energy -- growing out of its long-standing research aimed at measuring radiation-induced mutations in cells and combining that research base with the National Laboratories' exceptional computational abilities. Similarly, the Laboratories have played a major role in establishing and shaping the research agenda in high energy and nuclear physics, plasma physics, nuclear medicine, nuclear engineering, supercomputing, and global climate modeling.

Scientific excellence and leadership has earned an impressive array of scientific awards to the Department. More than 58 Nobel prize winners since 1936 have been supported by the Department of Energy at some time in their careers. Eighteen Nobel prizes have been awarded to Department of Energy laboratory employees, and another 13 to researchers who employed National Laboratory facilities in their award-winning discoveries. Most of the 40 winners of the prestigious Enrico Fermi Presidential awards have done research supported by the Department. Many additional award and distinctions have been presented to Laboratory employees for their contributions in science and technology, including from the National Academy of Sciences, Smithsonian, American Physical Society, and many other scientific organizations.

New facilities under construction by the Department promise continued scientific discovery and world leadership. For example, new ultra-violet and X-ray radiation sources at the Lawrence Berkeley Laboratory and

User Facilities: Creating New Windows on the World

Dow Chemical is involved in a research partnership with one of its commercial competitors, DuPont, along with Northwestern University, at the Advanced Photon Source at the Argonne National Laboratory. The three partners have joined to form a Collaborative Access Team that will conduct research on materials such as catalysts, fibers, engineered polymers, plastic and metal finishes, and electronic materials. As explained by Dow's Vice President and Director for R&D, "The Advanced Photon Source will let us look at materials in ways never before possible. It will be like seeing in color what you've only seen before in black and white."

[13] *Science in the National Interest* delineates five major goals for continued stewardship of the nation's basic science enterprise; for the purposes of this White Paper, the fourth and fifth goals--which both address training and education--are combined.

at the Argonne National Laboratory will enable studies of the structure of metals, alloys, ceramics, polymers, and biological molecules, such as proteins and viruses. These studies hold the potential for revolutionary advances in understanding of materials and could result in major future commercial applications in products ranging from fabrics and plastics to designer drugs and computer chips.

Although the Department's laboratories have a long record of scientific excellence, the challenge is to achieve continuous improvement during a period of scarce resources. The following strategies will help the Department contribute to the National goal of maintaining leadership across the frontiers of scientific knowledge:

- Concentrate and sustain clear areas of world-class scientific excellence.

- Maintain a proper balance between fundamental research, applied research, and technology development and demonstrations.

- Strengthen and expand utilization of peer review throughout laboratory programs to ensure the best scientific and technical performance.

- Sustain and bolster international coordination, especially when large scientific facilities are required.

2. Goal: Enhance Connections Between Fundamental Research and National Goals

The Department of Energy has major National mission responsibilities in the areas of energy resources, national security, fundamental science, and environmental quality. The Department has invested heavily in science and technology to uphold these responsibilities. Science at the National Laboratories in support of these areas is wide-ranging, encompassing both long- and short-term basic and applied research. However, in order to meet the Department's challenging goals for the future, the connections between fundamental research and mission objectives will need to be tighter than ever before.

- ***Energy Resources***: The Laboratories have played a major role in examining the fundamental behavior of materials involved in the generation and use of energy, and in studying energy production and conversion phenomena essential for future energy security. For example, Laboratory research involving crystalline silicon and thin film photovoltaic substrates have contributed to major advances in solar energy. Work by the Laboratories on basic combustion dynamics has translated into more efficient automotive engine designs. Research by the Laboratories on biochemical and thermochemical processes may ultimately pave the way for widespread future utilization of biofuels. Similarly, basic advances in plasma physics and materials science has been essential to major recent accomplishments in fusion research, which could become a major energy source in the future.

- ***National Security***: The nuclear weapons, arms control verification, and nuclear non-proliferation activities of the Laboratories have depended upon, and helped facilitate, a comprehensive understanding across a range of scientific disciplines, including physics, chemistry, mathematics, materials science, and computational science. With the cessation of underground nuclear testing, basic science will play an even greater role than it has in the past in providing the basis for safe and secure stewardship of the nuclear stockpile. To meet their national security missions in the future, the Laboratories will need to develop a stronger scientific base within the weapons program through enhanced computation and simulation activities, and through more advanced work in areas such as inertial confinement fusion, materials science, neutron radiography, and pulsed power. Science, and not nuclear testing, will be the foundation for maintaining confidence in the safety and reliability of our nuclear deterrent.

Selected Accomplishments of the National Laboratories that have contributed to U.S. Science and Technology Leadership

	High-Energy Physics
1950's	Study of cosmic rays gives way to studies of particles and their interactions leading to the construction of the world's largest accelerators, the Bevatron and the Cosmotron.
1970's	The development of the Standard Model provides the first unified theory of matter and sets the stage for all new experimental devices. US is acknowledged leader in the world, in both experiment and theory.
1990's	Discovery of the top quark at the Tevatron is imminent which will cap a 16 year international quest to complete the experimental verification of the Standard Model.
	Atomic and Nuclear Physics
1950's	Fundamental research in atomic and nuclear phenomena led to nuclear magnetic resonance and the underlying physics of the laser.
1970's	Practical high-power and semiconductor lasers developed.
1990's	Applications of lasers in communications, medicine, consumer electronics; magnetic resonance imaging for medical diagnostics.
	Biomedical Science
1950's	Research on the effects of radiation on cells and genetics,
1970's	Developed the computer axial tomography (CAT scan) and positron emission tomography (PET scan) medical diagnostic techniques.
1990's	Human genome sequencing and mapping; major advances made in structural biology.
	Materials Science
1950's	Provided the understanding of carbon composite structures which led to the extensive use of graphite-based materials. Research in radiation damage led to new materials resulting from ion implantation techniques.
1970's	Developed electron beam and laser annealing processes leading to major semiconductor manufacturing technologies. Developed fracture-resistant steels and produced the first metallic glasses.
1990's	Achieved world records in performance of: photovoltaic energy conversion; organic superconductors; superconducting wires, tapes, and devices; batteries and fuel cells. Developed flexible, polymer-based electrolytes; lead-free solder; high-temperature, high-strength intermetallic alloys; and superior welding methods. Discovered world's first magnetic polymer.
	Fusion Energy
1950's	The Atomic Energy Commission is one of the world's leaders in initiating the theoretical and experimental foundation of magnetic confinement fusion.
1970's	The Energy Research and Development Agency begins construction of the world-class Tokamak Fusion Test Reactor. The U.S. fusion program is acknowledged to be the world's leader in the field.
1990's	The Department of Energy's Tokamak Fusion Test Reactor achieves world record in controlled fusion energy production. The magnetic fusion program moves toward internationalization of its effort and transfer of its technology to U.S. industry. Inertial fusion provides the technical base for nuclear stockpile stewardship.

- ***Environmental Quality***: The Laboratories have performed a wide range of research in areas that contribute to our understanding of environmental contamination, environmental systems, and pollution prevention and mitigation. For example, the Laboratories are at the forefront of research on air pollution and its movement through the atmosphere. This work, with origins related to the study of atmospheric nuclear testing, focuses on areas including atmospheric chemistry, acid rain, stratospheric ozone depletion, and global climate change. The Laboratories have played a major role in developing increasingly sophisticated climate models and are developing the elements of a comprehensive Earth-systems model that integrates the impact of human and natural activities on the Earth's environment. Environmental research also is being performed at the Laboratories in ecosystem functioning and responses to change, bioremediation, hydrology, and health risks from low-level exposure to energy-related chemicals. These areas of research have led to the development of environmental technologies and integrated ecosystem management, and will be essential for helping meet the estimated $300 billion nuclear clean-up challenge which is a legacy of the nuclear weapons production program.

The following strategies will help the Department contribute to the National goal of enhancing the connections between fundamental research and national needs.

- Increase joint planning of research programs and technology development programs.
- Invest in research that supports the development of environmental, national security, and energy technologies.
- Examine opportunities for enhanced leveraging of the R&D base for meeting mission needs.

3. Goal: Stimulate partnerships that promote fundamental science and engineering and effective use of physical, human, and financial resources

Partnership mechanisms for working with the DOE Laboratories include consulting agreements for university professors, long-term guest assignments for industrial and foreign researchers, user programs for major facilities, cost-shared contracts, and Cooperative Research and Development Agreements (CRADAs). The first two mechanisms are particularly effective in promoting broad-based fundamental research.

Partnerships with university and industrial scientists and engineers are a central operating approach at the DOE Laboratories. This is evidenced, for example, by the more than 20,000 scientists and engineers who were guests at the multi-program laboratories in 1993; approximately one-third were from industry.[14] At the Oak Ridge National Laboratory alone last year, guest scientists and engineers numbered almost 4400, more than double the number five years earlier. Of these, 1700 were industry participants, an increase of 22 percent over the number in 1991. These guests represented the equivalent of about 1500 additional full-time laboratory scientists, effectively doubling the productive scientific workforce at Oak Ridge. Experience at the other National Laboratories is similar. These partnerships are helping the productivity and vigor of the laboratories while benefiting industry and contributing to the Nation’s science and technology enterprise.

[14] Guests are researchers who visit and work at a laboratory for a period of ten days or more. A much larger number of people (over 200,000) visit the laboratories for shorter periods of time to do research or to talk with laboratory staff, or to tour the site.

Assignments of faculty, students, and industrial scientists to laboratories generally are paid for by the supporting organizations.[15] In addition, companies invest significant funds at the laboratories in support of experimental use at user facilities, such as the Department's advanced light sources. At the National Synchrotron Light Source at the Brookhaven National Laboratory, many industrial users have spent $2 - $3 million apiece to provide the beam line equipment for their experiments. Since this equipment is of use only to the facility, it is left behind for other users when the industrial partner has completed its work. Costs for beam lines at the new Advanced Light Source and the Advanced Photon Source are substantially greater because of the greater complexity and capability of the facilities. Access to the beam lines at these new facilities has already been claimed by dozens of teams of government, academic, and industrial users. The total investment so far by industry in equipment at DOE light sources is in excess of $100 million.

The Department currently has more than 1000 CRADAs with over 700 industrial partners. While the majority of these partnerships are related to specific product or development efforts, almost 20 percent involve basic research. An even larger fraction involve work that has grown out of previously sponsored basic research. The Department and the Laboratories continue to seek CRADA arrangements with companies interested in advancing basic science.

Improved partnership arrangements could further promote the effectiveness of the Laboratories, and increasingly are essential in meeting National needs. The following strategies will help the Department contribute to the National goal of stimulating additional, effective partnerships that promote science and engineering:

- Further expand utilization of laboratory user facilities through simplified access by industry and universities.

- Increase opportunities for remote, "on-line" access to Laboratory research facilities. This service will eventually greatly expand access to user facilities by scientists, engineers, and even classrooms, through access via public communication networks such as Internet.

- Further streamline CRADA and other technology partnership procedures to shorten the time and reduce the complexity of finalizing agreements.

- Continue to seek CRADA arrangements with companies interested in advancing basic science.

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[15] Sometimes the costs are covered by a separate university or industry research contract with the government, but not by the laboratory.

4. Goal: Produce the Finest Scientists and Engineers for the Twenty-first Century and Raise the Scientific and Technological literacy of all Americans

DOE has capabilities that distinguish it from other agencies and institutions and allow it to make significant contributions to this National goal. The laboratories' large scientific work force, geographic diversity, world-class scientific facilities, technology development expertise, and capabilities in forming partnerships allow the Department to provide technical training and public enrichment experiences throughout the country. These facilities are major sites for undergraduate and graduate research performed as part of the normal educational curricula for thousands of students.

College and university-based education programs have been supported since the early days of the Atomic Energy Commission through student fellowships and research opportunities, curriculum development, and faculty enhancement. Undergraduate programs are conducted at both two-year and four-year institutions. Graduate and post-doctoral programs enhance research opportunities through fellowships at home institutions and Department of Energy facilities. Representative undergraduate and graduate programs include:

- The Science and Engineering Research Semester, which provides the opportunity for science and engineering students to participate in research during an academic term at seven of the Department's National Laboratories.

- The Faculty/Student Team Research program, which supports participation of faculty members with a small group of undergraduate and graduate students in on-going research at Department of Energy facilities.

The Department also makes significant contributions to all levels of mathematics and science education to help enhance the literacy of the public in science, mathematics and engineering. The Department's funding for pre-college education programs (K-12) has increased by approximately 400 percent over the past five years, reflecting the growing understanding that these early learning years are extremely important in motivating and retaining students' interest in mathematics and science.

The Department's pre-college programs improve the skills and knowledge of new and existing teachers, provide alternative learning environments, encourage curriculum reform, disseminate new materials and media, provide equipment and technical assistance to teachers, foster research on new methods and materials, and provide opportunities for students and teachers to perform research on current science and technology. Specific examples of DOE programs developed with or by the National Laboratories are:

- The National Science Bowl, an annual competition involving roughly 12,000 high school students nationwide.

- The Bay Area Science and Technology Education Collaboration, a multi-laboratory teacher enhancement program to improve math and science education in the Oakland Unified School District for grades K-12.

- The Teachers' Academy for Mathematics and Science in Chicago has set a goal of retraining over 15,000 math and science teachers in grades K-12 in this largely minority, largely poor urban system. This initiative emerged from collaborations by the Fermi National Accelerator Laboratory and Argonne National Laboratory with universities, museums, teachers' colleges, corporations and citizens' groups.

- Becoming Enthusiastic About Math and Science (BEAMS) brings fifth and sixth grade classes, with their teachers, to the Continuous Electron Beam Accelerator Facility (CEBAF) in Newport News, Virginia for a modified academic week.

- The New Explorers series of PBS television programs on topical science and technology issues, uses teaching materials developed under the leadership of Argonne National Laboratory.

The following strategies will help the Department contribute to the National goal of producing the finest scientists and engineers for the twenty-first century and raising the scientific and technical literacy of all Americans:

- Maintain excellence in recruiting scientists and engineers to the laboratories for continued intellectual renewal of these institutions and training of top graduates at the frontiers of science and technology.

- Strengthen laboratory interactions with universities.

- Continue to focus on pre-college enrichment educational programs for underrepresented populations.

- Continue to integrate education programs into the activities of the laboratories.

D. Conclusion

"Science reveals new world's to explore, and by implication new opportunities to seize and new futures to create." This statement by Vice President Al Gore[16], quoted in Science in the National Interest, captures the importance of a strong National investment in science and technology. For the Department of Energy and its laboratories, science and technology are the currency for meeting our mission requirements. The Laboratories support world-class scientists and engineers and unique, advanced research facilities which, help address complex, multi-disciplinary problems in areas ranging from national security to fusion energy to environmental clean-up.

The research facilities at the Laboratories provide access for thousands of academic and industrial scientists to new frontiers in areas such as materials science and molecular biology. In this fashion, and by virtue of their distinguished record of scientific accomplishments, the Laboratories represent a National asset that warrants careful

[16]The statement was made by Vice President Gore to the Forum on Science in the National Interest in February, 1994.

stewardship during an era when science holds the potential for addressing major National needs in health care, environmental quality, national security, and sustainable development. The Administration's new science policy provides the framework for helping sustain and guide the Department's scientific facilities and programs in the face of tight competition for resources. These facilities, like basic science in general, have provided a means of discovery and a record of technological innovation. The dividends of this investment will continue to accrue for generations to come.

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III. Peer Review at the Department of Energy

A. Introduction

Merit review with peer evaluation is a powerful and effective tool for enhancing relevance and productivity in Federal research and development (R&D). Despite some of its well-documented shortcomings,[17] peer review stimulates competition, establishes high standards for quality, rewards productivity, and, on balance, fosters creativity and promotes fair play. When combined with energetic and visionary R&D program leadership, peer review can marshal highly competent R&D teams, focus scarce resources on the most important and potentially fruitful technical opportunities, and provide reasonable assurances to taxpayers that their Federal R&D dollars are being prudently invested.

On May 6, 1994, in a White House memorandum, the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) established merit review with peer evaluation as an "R&D policy principle" to be incorporated in all Federal agency R&D budgets for Fiscal Year 1996. Specifically, according to the memorandum, each Federal R&D agency is expected to

> ***"significantly enhance the utilization of merit review with peer evaluation and competitive selection in Federal R&D projects. Research not subject to merit review with peer evaluation is expected to decline and funding in these areas should be moved into areas of merit-reviewed research with peer evaluation."***

Further, increasing concern about accountability for efficient and productive use of government funds, including funds for government-supported R&D, has been reflected in recent Federal legislation and executive direction. The Chief Financial Officers Act, the Government Performance and Results Act, the Competition in Contracting Act, the revision of the Federal Acquisition Regulation, the National Performance Review initiative, and a number of other program evaluation initiatives from OMB have all had a profound effect on Federal agency management, oversight, and conduct of R&D programs.

The Department of Energy (DOE) fully embraces these principles of accountability, competition, and objective merit review, including peer review. In fact, it has already put in place many new ways of doing business that are strengthening their application. This paper documents the Department's continuing and expanding commitment to these principles and, in particular, to peer review.

[17]Chubin, Daryl E. and Hackett, Edward J., *Peerless Science: Peer Review and U.S. Science Policy*. (Albany, NY: State University of New York Press, 1990).

B. Scope of Peer Review at the Department of Energy

At the Department of Energy, peer review means competent, qualified, objective, and formal evaluation using (1) specified criteria and (2) the review and advice of qualified peers. To be qualified, peers must be technically competent in the scientific and technical field under review. Peers may come from any source, including industry, academia, and government agencies and associated laboratories. To be objective, peers must be reasonably independent and free from conflict of interest. The results of peer reviews must be recorded and, under appropriate controls, accountable to further review.

Merit reviews meeting these criteria take on many and diverse forms. They are applied to R&D proposals, projects, and programs. They are applied, as well, to the design and acquisition of major research facilities and to the formulation of multiyear research plans and strategies. Appropriate forms of peer review are constructed and applied to activities at various organizational levels: the Department Secretary, Assistant Secretaries, program offices, National Laboratories, integrated laboratory R&D, research subcontractors (including universities), and laboratory user facilities. The nature of peer review at each level is tailored to the needs at that level.

Peer reviews are usually undertaken in the context of the allocation and use of scarce R&D resources. They may be used in conjunction with competitive selection processes, where peer reviews take place prior to the award or approval of a grant or contract, or where the research activities are chosen from a pool of qualified applicants following peer reviews. These types of peer review are called pre-award, or *prospective*, reviews. Peer reviews may also be used in conjunction with evaluations of ongoing or recently completed research. These in-progress or performance reviews are called post-award, or *retrospective*, reviews. These latter reviews also strongly influence the allocation of R&D resources by what is sometimes referred to as selection by competitive survival.

Although the terms *prospective* and *retrospective* are useful constructs to describe *when* merit reviews with peer evaluation take place, the substance of both types of reviews are quite similar. In both cases, the merit of an investigator's or research group's record of accomplishments (retrospective considerations) *and* the projected course of future research (prospective considerations) bear directly on the evaluation.

1. Statutory and Regulatory Context

The Department of Energy, like other Federal R&D agencies, must carry out its scientific and technical missions within a larger context of statutory, regulatory, and procedural requirements governing the expenditure of R&D funds. This context varies for different programs, but in each case largely determines the way in which peer review principles and methods are applied.

The award of research contracts, for example, is governed by the Federal Acquisition Regulation and the Competition in Contracting Act, both of which require competition among bidders and formal selection processes. The Department employs peer review principles and methods, including the use of independent engineering and scientific reviewers, in the technical evaluation stage of all such selection processes related to R&D, except in relatively rare instances where sole-source selection may be justified.

Further, the award of research grants and cooperative agreements is governed by the Department's Financial Assistance Rules, as promulgated in the Code of Federal Regulations (10 CFR Part 600). The Department's major research organizations have promulgated formal rules in the CFR governing the merit review process for R&D financial assistance. These rules require the use of technical experts to perform credible merit reviews of all applications, solicited and unsolicited. Such merit reviews may make use of standing committees, ad hoc committees, or field readers, and generally include, in the spirit of peer evaluation, at least three qualified persons from outside the awarding program office, in addition to the designated contracting officer's representative.

A combination of Federal and Departmental regulations also governs the award of contracts at the Department's laboratories. Under the Federal Acquisition Regulation, a management and operating (M&O) contract is recognized as an appropriate instrument, or agreement, under which the government

> ***"contracts for the operation, maintenance, or support, on its behalf, of a government-owned or controlled research, development, special production, or testing establishment wholly or principally devoted to one or more major programs of the contracting Federal agency."***

Such M&O contracts permit the Department to draw upon, nurture, and maintain the special technical expertise and capabilities required for unique missions, such as those associated with nuclear weapons and large, multidisciplinary, integrated, non-weapons research. Over the years, the Department's missions and associated requirements for such specialized expertise and capabilities have given rise to the Department's laboratory system. Altogether, the replacement cost of the facilities of this system is currently estimated to exceed $30 billion. The laboratories employ about 50,000 people, representing a concentration of technical talent that includes more than 8,500 Ph.D.s and several Nobel laureates.

Examples of specialized research facilities located at these laboratories include accelerators for the study of high energy physics, the world's most powerful computers and lasers, synchrotron light sources for probing the structure of materials, facilities for producing medical isotopes, and instrumentation laboratories for characterizing the details of flame propagation and combustion. The Department owns and maintains these facilities and, with the exception of the classified facilities, makes them available to researchers from all sectors of the economy, public and private. The Department underwrites the operating costs for experimenters who openly share their data with the scientific community. Commercial users may also use the facilities to conduct proprietary research, but on the condition that they participate on a full-cost-recovery basis. Peer review is routinely employed to allocate available time and select the experiments conducted at the major research facilities, with some facilities having waiting lists exceeding a year.

Under a DOE-initiated contract reform[18], the Department's M&O contracts now require, or will soon require, regular performance-based merit reviews to ensure accountability in M&O contractor performance. M&O contracts that do not now contain such requirements will incorporate them when the contracts come up for renewal or renegotiation. In addition, all laboratories have an array of outside advisory panels that periodically review and advise on the relevance and productivity of laboratory-conducted R&D.

Finally, one M&O contractor seldom performs all of its R&D tasking by itself. Whether under a lead-laboratory or other management arrangement with the Department, a portion of the R&D is typically subcontracted to universities, private laboratories, or other R&D performers. At the National Renewable Energy Laboratory, for example, one-half of the laboratory's total funding supports research subcontracted to outside R&D performers. At Argonne National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest Laboratory, this figure varies between 10 and 20 percent. At other laboratories, this figure is less. All such subcontracts, likewise, are governed by contract provisions that generally require both competitive selection processes, which in the case of R&D generally involve merit reviews with peer evaluation, and periodic evaluations of contractor performance.

2. R&D Programs Subject to Peer Review

The Department's overall R&D budget for Fiscal Year 1994 is estimated, depending upon one's precise definition of R&D, to be about $7.4 billion, as shown in Appendix A. This amount may be grouped into three broad, roughly equal, categories: fundamental science and energy research ($2.4 billion); civilian energy technology and related R&D ($2.8 billion); and national security R&D ($2.2 billion).

Of the $7.4 billion total, approximately 20 percent supports research carried out by R&D performers employed outside the Department and its laboratory system. Performers include industry, universities, public and private research institutions, and R&D consortia. The instruments used to convey funding to these R&D performers include Department-awarded grants, cooperative agreements and contracts, and laboratory-awarded research subcontracts.

Of the remaining 80 percent, most supports research and related activities carried out by performers within the Department and its laboratory system. Of this, approximately 40 percent supports the operation, maintenance, construction, and modernization of the specialized research and related user facilities. Another 35 percent supports internal laboratory research programs. The remaining 25 percent supports other functions, including general infrastructure (for example, roads, utilities), overhead, and other indirect costs.

The mix of R&D activities calls for a variety of approaches to managing research and applying peer review principles and methods. For example, research by outside R&D performers, because of the nature of the procurement instruments used to convey funding, is governed by statutory and regulatory requirements that require, in one form or another, merit

[18]U.S. Department of Energy, "Making Contracting Work Better and Cost Less; Report of the Contract Reform Team." (Washington, DC: U.S. Department of Energy, February 1994).

reviews, mostly with peer evaluation, in conjunction with pre-award competitive selection processes. The M&O contracts are, likewise, competed and regularly evaluated, with increasing emphasis on specific performance-based measurement criteria. Also, because experimental time on the special facilities is so highly valued and demand exceeds supply, virtually all access to the facilities is allocated through some means of merit review with peer evaluation.

Peer review coverage of the internal research programs at each laboratory is, likewise, varied. The greater portion is subject to retrospective merit reviews, called for by management and conducted most often by scientists who are independent of the laboratory, in conjunction with outside program reviews and advisory committee oversight. A lesser portion is subject to prospective peer review as exemplified somewhat narrowly by the highly successful laboratory directors' discretionary R&D program and more broadly by the many programs managed within Departmental headquarters that apply peer review principles and methods to the evaluation of laboratory Field Work Proposals. This latter process is illuminated later in this paper.

Even though the Department applies different peer review methods to guide its research programs, both outside and internal, a sampling of R&D projects, using retrospective merit review by independent experts, provides evidence that research quality and relevance of both types of research programs are comparable. For example, an organization within the Office of Energy Research (the Office of Program Analysis) regularly conducts, at the invitation of R&D program managers, retrospective peer reviews of R&D programs throughout the Department. Using an interactive method with independent, outside expert reviewers, this organization has evaluated more than 2,700 research projects over 12 years, covering about 20 percent of the Department's civilian basic research and technology development programs. The most recent data, which includes 744 research projects in Basic Energy Sciences conducted at both national laboratories and universities, produced results showing that the research programs of both internal and outside R&D performers shared nearly identical statistical profiles on research quality and relevance. These retrospective peer reviews, it should be noted, are in addition to other reviews administered by the program managers and serve as an independent measure of research quality and relevance.

Finally, above the project level, at higher levels of decisionmaking in the organizational hierarchy, the Department makes extensive, although not comprehensive, use of expert advisory bodies, constituted under the Federal Advisory Committee Act, and the National Academies. Peer input is also obtained from workshops, technical society meetings and symposia, and extensive publication in the peer-reviewed literature.

C. Current Peer Review Practices at the Department of Energy

The scientific and technology development missions of the Department of Energy are extraordinarily diverse and far-ranging. The Department is among the largest supporters of fundamental science and basic research across many disciplinary areas and technical fields. Its applied research and technology development programs concentrate primarily on the Department's energy, environmental, and national security missions, but in doing so embrace countless forefront areas of research vital to industry, commerce, and trade. The Department also builds and equips many of the premier R&D facilities vital to U.S. competitiveness and used by U.S. universities, corporations, and nonprofit research institutes.

In these respects, the Department is endowed with highly valuable R&D resources for which there is intense competition. The Department has found over the years that this competition is most productively and equitably managed by merit review practices that involve objective reviews and advice, that is, by peer review. It has also found, however, that peer review practices must be appropriately tailored to each context, depending on the nature of the research activities performed and the R&D community served.

Finally, and importantly, peer review systems at the Department do not now, nor must they in the future, preclude the possibility of initiating some research programs without peer review. Preserving this flexibility is vital. Programs representing entirely new research directions, research at the interfaces between established communities, or essential elements in critical mission areas often do not survive traditional peer review. If the Department had applied peer review rigidly, without flexibility or regard to such weaknesses, it might not have funded Dr. Luis Alvarez, whose work ultimately led to the meteor-impact theory of the extinction of the dinosaurs. This was world-class science -- neutron activation analysis of iridium anomalies in soil samples at the Cretaceous-Tertiary geologic boundary -- that used the Department's skills and facilities in novel ways that led to a revolution in thinking about our planet and its history.

1. Fundamental Science and Energy Research

Virtually all of the Department's fundamental science and energy research programs undergo merit review of one form or another in order to ensure scientific excellence and mission relevance. Peer evaluation is used extensively in these merit review processes.

Nearly all research conducted by R&D performers outside the Department and its laboratory system is governed by formal processes of prospective merit review with peer evaluation and competitive selection. Such processes are codified under the Office of Energy Research's Financial Assistance Program (10 CFR Part 605), which, with some exceptions for flexibility, requires each funded grant proposal to receive a minimum of three external peer reviews. Proposals are peer reviewed for scientific excellence. This process shares many features of the merit review system of the National Science Foundation. Performance is also reviewed as part of all renewal proposals, which typically occur on three-year cycles.

Internal research programs at the Department's laboratories, likewise, undergo merit review. These reviews consist of a mix of prospective and retrospective reviews, and in many cases, both. They employ varying degrees of peer evaluation at both the laboratory and Departmental oversight levels, including regular annual reviews of program management and onsite project reviews by Departmental staff. In addition, all labs, user facilities, and major research divisions have visiting committees of outside experts that provide annual peer review of research relevance and quality.

Every internal laboratory research program is also reviewed annually by Headquarters as part of the laboratory Field Work Proposal (FWP) submission process, in accordance with the provisions of the governing M&O contracts. Field Work Proposals are the means by which the laboratories formally propose future work and seek authorization for expending R&D funds. Field Work Proposals may vary in the extent of their specificity, but in those programs that depend heavily on the use of prospective peer review in approving laboratory R&D funding, FWPs are required to be of peer review quality. Such practices are routine in the Office of Health and Environmental Research, the Experimental Plasma Research portions of the Fusion Energy Program, several major divisions of Basic Energy Sciences, and others.

In the Office of Health and Environmental Research, for example, all FWPs are required to be of peer review quality and to be externally reviewed by independent experts. Regardless of merit review method, all research projects are annually reviewed, and any project may be redirected or terminated as a result of these reviews. All new proposals are subject to merit review with peer evaluation.

Because one of the primary goals of all scientific research is to advance the forefront of knowledge, publication of original work is an essential element of the overall research activity. DOE-supported scientists, whether outside R&D performers or internal to the laboratories, are continually evaluated by the quality of their original research as published in archival, peer-reviewed journals. This publication of original work in the open literature in itself constitutes another and important form of peer review. The Department relies upon it to both guide and gauge the relevance and productivity of its internal research activities.

The Department also makes extensive use of the National Academy of Sciences and a number of standing committees constituted under the Federal Advisory Committee Act. The Office of Energy Research, for example, routinely obtains advice on program content, quality, future direction, priorities, and proposed facilities from the Basic Energy Sciences Advisory Committee, the Health and Environmental Research Advisory Committee, the High Energy Physics Advisory Panel, the Nuclear Sciences Advisory Committee, and the Fusion Energy Advisory Committee. Their expert and independent nature enable these advisory committees to provide additional and valuable outside advice used to guide the Department's R&D activities at the overall program level.

2. Civilian Energy Technology and Related R&D

The objectives of the civilian energy technology and related R&D programs, such as those focused on energy efficiency, pollution prevention, environmental management, renewable energy, coal, oil, and natural gas, largely aim at advancing technologies for use in the general economy. This means that the management and direction of such programs must involve not just technical experts, but also those who will ultimately manufacture, market, and use the technologies. This calls for collaborative modes of R&D review and conduct that fully engage participation among those who understand competitive markets and consumer demands.

Accordingly, many of the Department's energy technology development and related R&D programs are deliberately designed to accommodate industrial partners. In various ways, these industrial partners provide substantial opportunities for external merit review by engaging themselves as full participants helping to plan, execute, and commercialize the R&D.

In addition, the Department makes extensive use of R&D procurement arrangements that not only involve industry, but require cost-sharing by industry. Section 3002 of the Energy Policy Act of 1992 establishes minimum cost-sharing thresholds of 50 percent for technology demonstration and commercialization projects, and 20 percent for all other civilian energy research. The resulting contracts thus benefit both from the routine competitive selection practices, as prescribed in Section 935.016-1 of the Department of Energy Acquisition Regulation, and from one of the most severe outside tests of research relevance, that is, substantial financial investment from industrial R&D partners.

At the Department's national laboratories, there is likewise a significant degree of external review of, and internal competition for, the energy technology development and related R&D programs. Every laboratory has an array of industrial advisory panels employed to review the R&D activities of each of its major research divisions. Individual research investigators must continually submit to a battery of scientific and technical reviews, both prospective and retrospective. Prospective evaluations include merit reviews of individual work proposals, almost always involving internal peers and sometimes involving external peers. Prospective evaluations also include multilevel internal reviews of the laboratories' formally submitted Field Work Proposals before they are sent to Departmental headquarters. Retrospective evaluations are performed on all R&D projects at least annually, but more typically are performed as an integral part of the course of ongoing research -- by colleagues, laboratory superiors, clients at Headquarters, as well as by peer reviewers of research publications. In addition, retrospective evaluations using peer review are employed on an ad hoc or sampling basis to review ongoing research involving specific projects, cooperative research and development agreements (CRADAs), and other forms of joint R&D.

Input from peers is also obtained from contractor review meetings, workshops, technical society meetings, and symposia. Fossil Energy programs and Energy Efficiency programs have made use on a selective basis of the Office of Energy Research's Office of Program Analysis to conduct formal, independent, retrospective peer reviews of their applied research projects.

Peer review processes in some elements of the Department's civilian R&D programs are currently undergoing significant enhancement. The Technology Development program of the Office of Environmental Management, for example, is instituting peer review at the program level (see below), and is strengthening the use of “focus area review groups” at the sub-program level. Beginning in Fiscal Year 1995, laboratory Field Work Proposals, known in the Environmental Management program as Technical Task Plans, will be reviewed by teams of subject matter specialists from technical, regulatory, business, and stakeholder perspectives.

Virtually all major energy technology development and related R&D programs are periodically subjected to higher level overall program reviews involving extensive use of scientific and technical experts and industry stakeholders. The most visible of these are review committees of the National Academy of Sciences and the standing Departmental advisory committees constituted under the auspices of the Federal Advisory Committee Act. These bodies are asked primarily to comment on the content and direction of the R&D programs, including their 5-year R&D plans and associated strategic plans.

In the Technology Development program of the Office of Environmental Management, for example, top-level program reviews are conducted by the Environmental Management Advisory Board and, beginning in Fiscal Year 1995, a newly established Committee on Environmental Management Technologies of the National Academy of Sciences. Similarly, the Office of Fossil Energy is advised by the National Petroleum Council and the National Coal Council. Altogether, there are eight active committees advising the civilian energy technology and related R&D programs.

Finally, with the implementation of strategic planning and Total Quality Management principles throughout the Department, most key planning and programming decisions are now evolved in full view of and with broad participation from outside stakeholders. For example, the Department's recently developed multiyear plan for Integrated Resource Planning was distributed to 350 stakeholders in the electric and natural gas utility industry, with formal comments received from 40 reviewers. In the Department today, every such plan must evidence extensive use of outside independent participation, review, and comment.

3. National Security R&D

The Department's national security responsibilities require highly integrated, multidisciplinary, multiyear team efforts. These requirements are imposed by both the complexity and seriousness of the nuclear weapons enterprise. The Department must maintain its responsible stewardship of the nuclear weapons stockpile and preserve the special nuclear weapons technology infrastructure and core competencies that may be needed in future national security situations. At the same time, it must dismantle nuclear weapons and dispose of special nuclear materials, as specified by international agreement, and contribute to the enforcement of arms control agreements and to the prevention of the proliferation of nuclear weapons. The R&D needed to support these missions requires unique facilities, special materials-handling procedures, and highly classified know-how that, while amenable to technical review and peer review, are not always amenable to the same kind of peer review processes that are employed in the realm of unclassified research.

The Department has established, for example, formal peer review processes in the Office of Defense Programs. Weapons life-cycle activities are addressed by formalized joint Department of Energy-Department of Defense project teams whose members come from both organizations. The Nuclear Weapons Council provides a high-level mechanism for advising on Defense Programs directions. Interaction with the Department of Defense also provides close customer feedback on major aspects of program performance.

The Department also uses formal committees composed of outside experts to review or advise on Defense Programs, including the Safety, Security, and Control Committee; the Weapon Safety Advisory Review Group; and the Inertial Confinement Fusion Advisory Panel. The Containment Evaluation Panel and the Threshold Test Ban Review Panel have also reviewed issues related to nuclear testing.

Defense Programs also uses independent outside expert groups, such as JASON (a highly qualified advisory body of scientists), to review its classified programs. The National Academy of Sciences has also reviewed Defense Programs technical activities. A large amount of unclassified research conducted within the Defense Programs is published in open peer-reviewed journals. There is also a classified peer-reviewed journal to which laboratory researchers actively contribute.

In the case of nuclear device design and much of the related weapons science and technology, detailed review requires active expertise, and there exists no broad industrial or university base from which to draw such experts. Historically, technical competition has proven invaluable in this field and peer reviews are so designed into program activities in large part by the existence of two nuclear design laboratories, at Lawrence Livermore and Los Alamos. One-on-one interactions between researchers in highly classified but related fields at these two laboratories add considerably to the quality improvement process at both laboratories.

Sandia National Laboratory employs an effective means of intramural review, using “red teams” to ensure the safety and reliability of Sandia components and processes. Defense Programs has further established a formal interlaboratory (Los Alamos, Lawrence Livermore, and Sandia) peer review process for specific weapon R&D, certification, and surveillance activities. For example, every five years, with annual updates, Lawrence Livermore-Sandia and Los Alamos-Sandia teams in the Weapons Assessment Process conduct peer-reviewed studies of each other's stockpile weapons.

Recent M&O contracts for Los Alamos and Lawrence Livermore require the University of California to conduct annual science and technology self-assessments stressing external peer reviews with specific criteria. These are being implemented using evaluations by appropriately constituted external review committees of experts. These committees, taken together, evaluate all technical activities at these laboratories. The University of California President's Council Panel on National Security reviews the weapons programs of Los Alamos and Livermore. Panel members include technical experts drawn from outside the University of California and laboratory communities. These and other mechanisms are used to assess and maintain quality in these programs.

D. Comparisons with Other Federal Agencies

More than 20 Federal agencies carry out R&D programs. Of these, the Department of Energy's R&D program is one of the largest, being responsible for about 10 percent of the total Federal R&D budget of $72 billion in Fiscal Year 1994. In addition, the Department of Energy has perhaps one of the most diverse set of missions, complicated by the unique demands of nuclear weapons design.

Because of this diversity and size, the Department's R&D programs taken together resemble the many facets of Federal R&D programs as a whole. Similarly, the Department's application of peer review principles and methods share many of the strengths, as well as some of the weaknesses, of such practices as applied to Federal R&D in general. Other agencies, for example, use an array of peer review methods, at all organizational levels, to promote quality, relevance, and productivity in R&D programs. The Department, likewise, applies these methods to the different levels in the management process hierarchy, and to the different types of R&D activities, as is most appropriate to each situation.

The National Institutes of Health, the National Science Foundation, and many parts of the Department of Energy's fundamental science, health and environmental research, and basic energy sciences programs all have extensive external research programs in the physical and life sciences. Each agency uses similar prospective peer review methods, by mail, or by panels, before funding proposals. Some agencies with their own laboratories also make available their research facilities for the benefit of other users, such as the National Aeronautics and Space Administration's wind tunnels. Research at such user facilities, like that at the Department's facilities, is merit-reviewed using prospective peer reviews.

Like the Department of Energy, the Departments of Defense and Commerce (the National Institute of Standards and Technology), the National Aeronautics and Space Administration, and, to some extent, the National Institutes of Health (NIH) all conduct internal laboratory research programs. Each agency relies primarily upon in-progress, retrospective reviews for guiding and gauging its internal laboratory research.

In the area of basic research, the National Institutes of Health is an agency often cited as a model for emulation in its use of merit reviews with peer evaluation. Ninety percent of the research activities at NIH are external, and are subjected to a two-stage review process. In the first stage at NIH, a panel of 15 to 20 scientists, experts in the relevant field, read each proposal. Generally, three panel members review each proposal in detail against specified criteria and prepare formal briefs, while the other panelists familiarize themselves with each proposal. All panelists take part in a group discussion and vote formally. The panel then reports to a National Advisory Council for the second stage. Each institute of the NIH has a single National Advisory Council of at least 12 members, not all of whom are necessarily scientists (in most proposals, there are considerations beyond pure science).

Review of internal laboratory research at the NIH is conducted by the Board of Scientific Counselors for each institute. Each board consists of outside scientists chosen for their expertise related to each institute. However, it should be noted that many Board members are funded by the institute under review.

An authoritative critique[19] of the NIH peer review system concluded that (a) the excellence of the overall NIH research program is built on a variety of approaches to managing research, using both prospective and retrospective reviews; (b) prospective and retrospective peer review have different strengths and weaknesses, and encourage creativity in different ways; and (c) the overall NIH research program was best served by retaining prospective review in its external (for example, R&D support via grants) programs and retrospective review in its internal (for example, in-house laboratory) programs.

As strong as the NIH and other agency peer review practices appear to be, in each area where commonality exists among research kind (for example, basic research) and communities (for example, universities, research centers), the Department of Energy has well-established peer review practices that are quite comparable and, perhaps, better in some areas. This comparability notwithstanding, the Department can only benefit by examining more thoroughly and understanding more completely the best practices of other

[19]National Institutes of Health, “Report of the External Advisory Committee of the Director's Advisory Committee.” (Washington, DC: National Institutes of Health, April 1994).

agencies. To this end, the Department intends to continue its study of other agency practices, participate in interagency forums on peer review, and implement some pilot programs to test innovative approaches.

The sharing of peer review strengths, however, means that the Department may also share some of its weaknesses. The process of merit review with peer evaluation, in general, is under pressure and has been criticized by many in the research community, in part, due to its cost, complexity, administrative burden, lack of available peers, slowness, and questions about equity and fairness. Even with these concerns, however, peer review is still widely regarded as the best method available for allocating scarce R&D resources. Accordingly, the Department of Energy seeks ways to both respond to these concerns and develop improved peer review systems, as outlined below.

E. Conclusions and Opportunities for Improvement

As documented in this paper, the Department of Energy uses peer review extensively throughout its R&D programs to both guide research direction (prospective peer review) and gauge research progress (retrospective peer review). In many instances, both forms of peer review are applied to the same research activity. The Department's peer review practices in many of its more mature R&D programs may be counted among the best practices of all agencies. Peer review practices in some of the more recently established and growing R&D programs are evolving and being strengthened. Virtually all major R&D programs experience multiple levels of review by qualified and independent review and advisory committees.

External R&D activities conducted via grants, contracts, and cooperative agreements are governed by an elaborate system of statutory, regulatory, and procedural requirements that virtually ensure that the vast majority of R&D awards are subjected to merit reviews with peer evaluation and competitive selection. Internal laboratory R&D activities are likewise subjected to multiple reviews by peers, both prospective and retrospective, with increasing competition. Retrospective merit reviews with peer evaluation have been confirmed by independent studies as an effective means for promoting research relevance and productivity in the laboratories. Moreover, in many Departmental laboratory R&D programs, retrospective reviews are increasingly being supplemented by prospective reviews of laboratory Field Work Proposals, where appropriate. Administrative requirements for cost-sharing and joint planning of applied R&D with industry add further to the checks and balances of R&D management.

In April 1994, the Department reaffirmed its strong commitment to peer review in its strategic plan, *Fueling A Competitive Economy,* by specifying that an important “success indicator” for its science and technology programs is

> ***“quality of science, as indicated by favorable outside peer reviews and judgment of expert advisory committees.”***

Recognizing the importance of peer review, having surveyed peer review practices at other Federal agencies, and having reviewed the suggestions of such experts as Chubin and

Hackett,[20] Bozeman,[21] and Kostoff[22] for the evaluation and improved use of peer review, the Department intends to strengthen further its use of peer review, in forms appropriate to its missions, in all of its technical programs, and at all levels of decisionmaking.

In so proceeding, the Department recognizes that serious reviews can impose major costs on those being reviewed, as well as on the reviewers and supporting staff. Peer review systems can introduce significant delays in R&D program execution. If implemented too rigidly, peer review systems can stifle flexibility and creativity. The experiences of several R&D agencies suggest that it is possible to create elaborate systems of overlapping reviews that are unnecessarily complex and burdensome.

Being aware of these potential risks, the Department has identified three broad areas for improvement.

F. Enhanced Application of Peer Review

First, *while recognizing the need for flexibility and efficiency, the Department of Energy will seek to enhance the use and application of peer review at all appropriate levels of R&D program management and execution.*

- Peer review applied at the highest level of management checks the research agenda and helps to inform the processes that establish top-level guidance for R&D priorities throughout the agency. Filling a gap in such coverage, an advisory task force for strategic energy R&D, similar to those advising the Secretary on science and defense matters, will be chartered to serve this function under the auspices of the Secretary of Energy Advisory Board.

- Where appropriate, gaps will also be filled in the coverage of expert advisory committees at the Assistant Secretary level and in the use of outside expert peer reviews at the major R&D program level.

- Recognizing that outstanding leadership can often take R&D programs to great heights of accomplishment, the Department will include R&D program leadership, at both Departmental headquarters and in the field, as a specific element in future major R&D program reviews.

- In its laboratory system of Field Work Proposals, the Department will encourage enhanced quality of FWPs and the expanded use, where appropriate, of prospective merit reviews with peer evaluation of FWPs for new projects, emulating current practices of many of the Department's basic research programs.

- At the outset of new major R&D program initiatives, plans will be established, as appropriate, to apply peer review principles and methods at all suitable levels.

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[20] Chubin, Daryl E., et al., *op. cit.*

[21] Bozeman, B., “Peer Review and Evaluation of R&D Impacts”, in ed. Bozeman, B., and Melkers, J., *Evaluating R&D Impacts: Methods and Practice*, p. 79-98. (Boston, MA: Kluwer Academic Publishers, 1993).

[22] Kostoff, R., “Assessing Research Impact: Federal Peer Review Practices”, in ed. Kostoff, R., *Evaluation Review* vol. 18, No. 1, p. 31-40. (Sage Publications, February 1994).

- In implementing the Department's initiatives in contract reform, measurements of contractor performance, including M&O contractors, will be extended, as appropriate, to include an evaluation of the use of peer review principles and methods.

1. Improved Peer Review Processes

Second, *the Department of Energy's management of its peer review processes will be strengthened, including the establishment of guiding policies and principles, improved oversight, and broadened documentation of use.*

- The Department will build on the successful peer review record of many of its programs, and establish guidelines for conducting peer review at various levels of management, tailoring them to meet the particular information needs and unique features of the programs and missions to which they would apply.

- Periodic and random sampling will assess the use and effectiveness of the peer reviews and identify areas for improvement. This may also include broadened coverage of the in-progress peer review program currently under way in the Office of Energy Research.

- A process for linking peer review principles and methods and other evaluative activities to the Department's strategic planning, budget formulation, and performance management activities will be developed and implemented, in conjunction with related efforts responding to the Chief Financial Officer Act and the Government Performance and Results Act.

- The Department will explore ways to reward the effective use of peer review, including simplification of administrative procedures and relaxation of oversight controls, in areas where R&D excellence has been demonstrated.

2. Peer Review Research and Innovation

Third, *the Department will be a leader in examining peer review processes and best practices, and in developing and implementing recommendations for improvements in the application of peer review to today's science and technology environment.*

- As part of the Department's oversight of peer review practices and increased use of performance-based contracting, collection of data on the practice and nature of various forms of peer review will be established. Information on current peer review practices will address, to the extent practicable, methods, costs, and benefits, and identify areas of improvement.

- Research on improved methods for peer review will be encouraged and communicated. Tradeoffs must be addressed between accountability and scientific freedom, efficiency and thoroughness, as must issues of the effectiveness, robustness, responsiveness, fairness of review, and adherence to technical standards of good measurement, including validity and reliability.

- A study, including surveys of the literature and interviews with both private and Federal agency R&D managers, will examine the various models for conducting Federal R&D and propose innovative approaches to the application and use of peer review to the accomplishment of the Department's R&D missions.

- A series of pilot programs will be established to test the expanded use of peer review, or modifications of peer review, in areas where it is not now uniformly applied, or where prospective reviews might be beneficially substituted for some retrospective reviews, such as in some of the Department's internal laboratory R&D programs.

- While some parts of the Department have excellent peer review systems already in place, new criteria for selection and effective use of peers will be developed and added to Departmental guidelines, as needed. These criteria may address such issues as the competence and objectivity of peers and methods to deal with reviewer bias and dysfunctional group dynamics.

Appendix A

SCIENCE & TECHNOLOGY FY 92-94			
		FY 1993	FY 1994
	FY 1992	Adjusted	Adjusted
	Actual	Approp	Approp
Area	$M	$M	$M
FUNDAMENTAL SCIENCE & ENERGY RESEARCH			
Energy Research			
Biological & Environmental Research	369.5	380.6	412.3
Basic Energy Sciences			
Materials Sciences	253.4	273.3	271.6
Chemical Sciences	156.5	163.6	166.3
Energy Biosciences	24.4	25.5	26.6
Engineering & Geosciences	35.4	36.5	37.2
Applied Math Sciences	80.5	83.9	103.7
Advanced Energy Projects	54.7	11.0	11.2
All Other BES	155.5	258.1	173.8
Subtotal BES	760.4	851.9	790.4
Other Energy Research			
Advanced Neutron Source	0.0	0.0	17.0
University & Science Education Programs	54.1	55.9	57.9
Laboratory Technology Transfer	10.0	9.9	39.2
Multi-Program Laboratory Support	25.6	26.7	41.3
All Other	15.8	15.7	20.1
Subtotal Other ER	105.5	108.2	175.5
TOTAL ER	1,235.4	1,340.7	1,378.2
GENERAL SCIENCE			
High Energy Physics	618.4	606.1	617.5
Nuclear Physics	351.4	306.6	348.6
SSC Not Including Terminiation Costs	482.6	515.4	0.0
All Other	6.4	(21.7)	9.0
TOTAL GEN SCI	1,458.8	1,406.4	975.1
TOTAL FND SCIENCE	2,694.2	2,747.1	2,353.3
CIVILIAN ENERGY TECH DEVELOPMENT & RELATED R&D			
CLEAN COAL TECHNOLOGY			
Advance Appropriation - Round 4 & 5	460.1	525.0	400.0
Appropriation	(50.0)	(525.0)	(175.0)

TOTAL CCT	410.1	0.0	225.0
FOSSIL ENERGY R&D			
Coal	225.6	186.3	167.3
Petroleum	56.5	61.6	75.3
Natural Gas	63.2	79.5	96.1
All Other	95.2	86.7	92.0
TOTAL FE R&D	440.5	414.1	430.7
CONSERVATION R&D			
Transportation	109.3	138.6	178.6
Utility	4.7	4.9	6.8
Industry	96.7	111.7	125.0
Buildings	47.1	52.3	81.4
Policy & Management	2.7	3.6	4.7
TOTAL CONS R&D	260.5	311.1	396.5
RENEWABLES R&D			
Solar energy	174.3	186.2	252.3
Geothermal	26.9	23.2	24.0
Hydrogen Research	0.0	0.0	10.0
Hydropower	1.0	1.1	1.1
Electric Energy Systems	30.4	32.1	38.6
Energy Storage Systems	7.2	10.2	17.5
Policy & Management - CE	1.9	2.9	3.9
TOTAL RENEW R&D	241.7	255.7	347.4
NUCLEAR ENERGY			
Civilian Nuclear Power			
Light Water Reactor	61.9	57.8	57.6
Advanced Reactor R&D	60.0	59.2	41.8
Facilities	96.6	92.7	6.7
Subtotal Civ Nuc Pwr	218.5	209.7	106.1
Space-Related Programs			
Advanced Radioisotope Power	51.9	54.4	52.7
Space Reactor Power System	40.0	29.8	27.4
Space Exploration Initiative	5.0	0.0	0.0
Subtotal Space-Related	96.9	84.2	80.1
Others			
Oak Ridge Landlord	0.0	0.0	24.9
Test Reactor Area Hot Cells	0.0	0.0	1.4
Test Reactor Area Landlord	0.0	0.0	0.0

Adv Test Reactor Fusion Irridation	0.0	0.0	0.0
All Other Except Termination Costs	48.9	48.0	23.1
Subtotal Others	48.9	48.0	49.4
TOTAL NE R&D	364.3	341.9	235.6
ENERGY RESEARCH			
Fusion Program	332.2	335.2	343.6
URANIUM ENRICHMENT			
AVLIS	161.7	0.0	0.0
Alternative Applications	1.0	0.0	0.0
TOTAL UE	162.7	0.0	0.0
RADIOACTIVE WASTE R&D			
Nuclear Waste Fund Activities	275.1	275.1	260.0
Civilian Waste R&D	5.1	4.9	0.7
Defense Nuclear Waste Disposal	0.0	100.0	120.0
TOTAL RW	280.2	380.0	380.7
ENVIRONMENTAL RESTORATION & WASTE MGMT			
Technology Development Defense	286.3	333.7	397.5
Technology Development - Civilian	0.0	0.0	0.0
TOTAL ER & WM	286.3	333.7	397.5
ES & H - ENVIRONMENTAL R&D			
Epidemiology & Health Surveillance	47.7	49.5	49.2
TOTAL TECH DEVEL & REL R&D	2,826.2	2,421.2	2,806.2
NATIONAL SECURITY R&D			
Atomic Energy Defense Activities			
Weapons Activities - R&D	1,431.7	1,536.0	1,298.8
Naval Reactors Development	695.2	730.0	684.4
Nonproliferation & Verification R&D 1/	210.0	219.9	235.0
Educations Programs	49.9	52.6	0.0
TOTAL NATL SEC R&D	2,386.8	2,538.5	2,218.2

TOTAL DOE	7,907.2	7,706.8	7,377.7
1/ Estimated amount for FY 1992; actual amount not available.			

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IV. Core Technical Capabilities of the DOE Laboratories

A. Introduction

The Department of Energy Laboratories are the product of several decades of investment by the nation both in facilities and in a highly trained workforce of scientists, engineers, technicians, and other support personnel. This paper provides quantitative and qualitative information about the core technical capabilities of the laboratories, and about how these capabilities are represented in terms of the laboratories' budgets, personnel levels, replacement value of major facilities, industrial partnerships, patents and licenses, and R&D 100 awards.[23] Short narrative profiles for each of the nine multi-program laboratories and the National Renewable Energy Laboratory are provided to give a fuller picture of the distinguishing characteristics of these institutions.

B. Core Technical Capabilities

Over the past several years, the Department of Energy laboratories increasingly have been using the concepts of "core competencies" and "core technical capabilities" as a means of assessing and managing their key areas of technical strength. The core competency concept has been utilized effectively in the private sector as companies have worked to achieve enhanced focus and market expansion based on their firms' distinctive strengths.[24] In 1993, the Department initiated a process aimed at adapting the core competency methodology to the entire DOE laboratory system. That effort resulted in the first-ever characterization of the core competencies of the DOE laboratories.[25]

DOE defines a core competency *as a distinguishing integration of capabilities that enables an organization to deliver mission results and products to its customers*. The major criteria which the Department has used to determine its core technical capabilities are:

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[23] The R&D 100 Awards are given each year to innovations both in public and private institutions which hold a high prospect for commercial success. The Department of Energy laboratories have received more of these awards than all other federal agency laboratories combined; more than 50 percent of the113 award-winning DOE technologies between 1989 and 1992 already have been commercialized.

[24] C.K. Prahalad and Gary Hamel, The Core Competence of the Corporation, Harvard Business Review. May-June, 1990, pp. 79-91.

[25] The results of this excercise were reported in Changes and Challenges at the Department of Energy Laboratories: Report of the Laboratory Missions Priority Team. That report termed the major laboratory strengths as "core competencies." Others have commented that these more accurately are the "core technical capabilities" of the laboratories. For this purposes of this paper, the term core technical capabilities is used.

- ***Vital to Mission Delivery***: The core technical capabilities exist to enable the organization to achieve its current and future missions and/or strategic intent;

- ***Distinguishing***: The organization is recognized as being one of a few to achieve excellence in its areas of expertise;

- ***Comparative Advantage***: The capability enables the laboratory to add value to the solution of a broad set of national problems in a fashion that is distinctive from other R&D performers;

- ***Difficult to Reproduce***: The expertise and capabilities embodied by the invested resources are difficult for others to duplicate; and

- ***Demonstrated***: The capabilities have had prior or current effect when applied to problems of national importance; and

- ***Enduring Value***: Competencies have been built to enable the organization to satisfy past, present and future mission, and they need to be responsive to mission changes of the future;

These criteria helped lead to establishment of the following eight core technical capabilities for the DOE Laboratory System:

- ***Advanced Materials Synthesis, Characterization and Processing***. The laboratories employ more than 2,000 scientists and engineers in advanced materials R&D and operate state-of-the-art facilities for conducting materials synthesis, characterization, and processing. Synthesized materials include high-performance ceramics, metallic alloys, intermetallics, polymers, composites, aerogels, superconductors, semiconductors, and high performance magnetic materials. Materials characterization is conducted at diverse facilities throughout the DOE complex including synchrotron light sources, neutron scattering centers, microscope facilities, high-temperature materials laboratories, and centers for microelectronics technology development, design and fabrication. The labs also have unique resources for processing materials, such as actinides and actinide alloys, as well as forming and heat-treating exotic alloys, shaping ceramic composites, developing optical materials, formulating and applying aerogels, and depositing multicomponent thin films. *Working with industry, universities and other Federal agencies, the laboratories provide a vital resource -- including scientific user facilities -- for advances in materials technologies critical to future national needs in energy, environment, health, industrial competitiveness, and security*.

- ***Advanced Computing, Modeling and Simulation***. The high-performance computing core competency has been a major basis of weapons design for more than 40 years. This capability includes integration of theory, modeling, simulation and advanced computing, and networking for a wide variety of engineering and experimental designs. All DOE laboratories use networking and high-performance computing to address complex problems by integrating theory, modeling, and simulation. Major DOE laboratories also all have important classes of supercomputing capabilities including vector and parallel processing computer power. *Scientific computing is crucial to missions such as designing nuclear weapons, predicting global climate change, and conducting fundamental research. It also provides essential underpinnings for such emerging missions as enhanced oil recovery and artificial intelligence.*

- ***Advanced Manufacturing and Process Technology***. The DOE labs have extensive experience in assembling multidisciplinary research teams to address various technological challenges particularly in support of national security and energy needs. Teams have drawn on competencies in engineered materials and processes; engineering sciences; electronics and microelectronics; high-performance computing; rapid prototyping and testing; reliability physics and engineering; process characterization; and modeling and systems integration. Strengths in microelectronics, photonics, reliability engineering, materials and process development, and modeling have resulted in multimillion dollars of cooperative research and development agreements with segments of the U.S. semiconductor industry. *These production processes provide a technical and management foundation for the laboratories to make a significant impact on U.S. competitiveness through industry-driven initiatives*.

- ***Biosciences and Biotechnology***. These integrated and multidisciplinary capabilities enable development, use, and understanding of living organisms for genomics, structural biology, bioinstrumentation, health risk assessment, bioremediation, bioprocessing of fossil fuels, conversion of biomass to fuels and chemicals, biological solar energy conversion, and bioprocess engineering. The DOE laboratory complex contains an array of unique facilities that support biotechnology R&D, including synchrotron light sources, neutron sources, biomedical imaging systems, bioprocessing research facilities, transgenic mouse facilities, chromosome processing resources, clone libraries, and databases. The competency is built on expertise in biological, health and environmental sciences, chemical and physical sciences, engineering, instrumentation and high-performance computing. *This set of capabilities can promote human health, enhance environmental quality, develop more secure and safer energy sources, and improve the competitiveness of U.S. biotechnology firms*.

- ***Advanced Energy Technologies and End-Use Applications***. The laboratories possess expertise in a wide range of energy supply and end-use technologies including policy and risk analysis and energy, environmental, and economic modeling. In particular, the DOE labs constitute the world's leading resource in advanced nuclear energy technologies, including advanced fission reactors, space nuclear power, atomic-vapor laser isotope separation, and both inertial and magnetic fusion. The laboratories have provided the technical basis for commercial use of solar thermal, solar photovoltaic, wind, biomass and other forms of renewable energy sources and are developing energy storage technologies, supercapacitors and chemical fuel cells for automotive use, and cleaner fossil-fuel energy cycles. Also, lab-based superconductivity pilot centers work with industry to promote commercialization of high-temperature superconductors. *For the most part, these efforts could not exist outside the environment of multidisciplinary institutions such as the DOE Laboratories*.

- ***Environmental Science and Remediation Technology***. This emerging core competency is defined as characterizing, evaluating, and monitoring the environment as a complex system. It includes remediating past and present environmental insults and ensuring future environmental sustainability. Capabilities supporting environmental technology include earth sciences and engineering (atmospheric, oceanic, land surface and subsurface); chemistry and chemical engineering; physics; biology; materials; advanced computation and simulation; molecular sciences; robotics; societal phenomena; and information management. The labs take a broad-based approach to this work, ranging from fundamental science programs to technology development. *Maintenance of these capabilities will contribute to the national welfare by reducing the cost of environmental restoration and waste management at DOE sites, as well as at other federal agencies and industry. It also will significantly expand new scientific knowledge and contribute to a cleaner environment*.

- ***Nuclear Science and Technology***. This category includes a broad spectrum of disciplines, technical capabilities, and facilities essential to DOE's national security and civilian research missions. Unique strengths include nuclear and thermonuclear physics and the physical models and experimental capability necessary to model and verify complex phenomena. Applications include inertial fusion for civilian and military applications and magnetic fusion for energy production. Underlying capabilities include plasma physics, radiation transport, interactions with matter at extreme states, three dimensional hydrodynamics, and instrumentation and diagnostics for extremely fast, high-energy events. High-energy and nuclear physics programs encompass the fields of elementary particle physics (which strives to understand the basic structure of matter and fundamental forces) and nuclear physics (which studies how these particles and forces combine to form nuclei). This competency also encompasses physics, chemistry and technology of light, medium, heavy and transactinium radioactive materials, nuclear safety, security, intelligence and power applications. These capabilities are essential to the future DOE security mission in nonproliferation, dismantlement, safety, security, and stewardship of nuclear materials.

- ***Integrated Defense Science and Technology Competencies***. These enabling technologies and competencies, required for nuclear weapons development and testing, remain critical to maintaining nuclear deterrence and to guarding against nuclear weapons proliferation. Numerous spinoffs serve the commercial world. For example, seismology theory and instrumentation -- highly refined for nuclear weapons testing -- remain important for detecting treaty violations. And advances in the science are important for predicting volcanic action, understanding earthquakes, and for oil and mineral exploration. Other examples include electronics, navigation, computer science, aerodynamics, control of nuclear weapons and materials, atmospheric and other environmental sciences, accelerators, advanced manufacturing, and system engineering and rapid prototyping. The infrastructure provided by this competency allows an unequaled capability for solving complex problems of national importance in defense and industry.

C. Guide to Core Technical Capability Data Charts

The following pages provide data on the core technical capabilities of the Department's nine multi-program laboratories and the National Renewable Energy Laboratory. The information is provided in seven different measurement categories, with four pages of data per category. The measurement categories are listed below. The first three of each four-page set of data catalogues information according to the eight core technical capabilities described above. The fourth page in each four-page set captures data about five additional core technical capabilities for specific laboratories, plus a category labeled "other" which represents laboratory strengths that did not fit within the established core capability definitions.

1. ***Operating Dollars***: Data is for Fiscal Year 1993, based on Budget Authority provided by Congress. Operating budgets do not include construction funds.

2. ***Full-time Equivalent Employees***: Total staff, by core capability category, at end of Fiscal Year 1993.

3. ***Replacement Value of Facilities***: Data covers only those major facilities valued at greater than $25 million. Replacement cost based on rebuilding the facility on a "green field" site, without derivative utilization of other established buildings.

4. ***CRADAs with Industry***: The total number of Cooperative Research and Development Agreements from 1989 through the end of 1993. Approximately 600 CRADAs existed at the end of 1993. As of October 1994, the number had grown to more than 1000.

5. ***Value of CRADAs with Industry***: This chart provides cost-shared value of the operational CRADAs in effect at the end of Fiscal Year 1993.

6. ***Patents and Licenses***: For the year 1993, approximately 500 new U.S. patent applications were filed based on laboratory innovations and 410 licenses were awarded.

7. ***R&D 100 Awards***: These awards are given annually by R&D Magazine to institutions, both public and private, for innovations which have a significant prospect for commercial success. The data covers the award-winning technologies at the laboratories over the period from 1989 through 1993.

D. The Ten National Laboratories Reviewed by the Galvin Task Force

1. Argonne National Laboratory (ANL), Illinois

ANL is a multi-disciplinary R&D facility capable of conducting both large- and small-scale projects. Its wide ranging scientific and technical expertise often is called on to attack challenges ranging from nuclear non-proliferation to industrial technologies to basic research. The 4,800-member Lab staff aggressively pursues collaborative, technology-transfer partnerships with industry, university, and with other federal labs and agencies. Among ANL's core competencies are:

- ***Large Accelerator based User Facilities***: Design, team-building, construction, and operation of large accelerator-based user facilities, with emphasis on involving the user community in the total process -- such Lab-user partnerships often are guided by boards made up of members of industry, academia, and government.

- ***Nuclear Reactor Technology***: ANL is the only U.S. publicly funded institution with comprehensive skill in design and operation of nuclear reactors and related fuel cycle facilities. This competency is supports the development of reactor and fuel cycle technologies, safety engineering, design of reduced enrichment fuels, and operation and training for reactors overseas.

- ***Environmental Science and Technology***: Programs are devoted to R&D on advanced characterization and remediation technologies, and substantial work supporting site clean up for the DOE complex. ANL partners with Midwest manufacturers to address environmental issues, waste minimization, energy storage, and transportation technologies. ANL also is a full member in the national multilaboratory partnerships with the automotive and textile industries.

- ***Materials Research / Superconductivity***: ANL hosts the largest federally funded materials research program in superconductivity. As one of three DOE pilot centers for the commercialization of superconductivity, ANL conducts extensive research with industry, focusing on components for electric power systems.

Argonne's world class user facilities include the:

- Advanced Photon Source,
- Intense Pulsed Neutron Source,
- Argonne Tandem Linear Accelerator System
- Structural Biology Center, and
- High Performance Computing Research Facility.

2. Brookhaven National Laboratory (BNL), New York

BNL was founded in 1946 by nine Eastern universities which needed a convenient user facility where projects too large for any one of them could be built and operated. The Lab and its 3,500-member staff have been fulfilling that need ever since. BNL conducts basic and applied research on problems ranging from the top quark to superconductivity and from global change to advanced radiation therapy. BNL's major facilities and their competencies are:

Alternating Gradient Synchrotron (AGS): The AGS is a proton and heavy ion synchrotron with a maximum energy of 33 GeV and the highest flux of any accelerator of this energy. Three Nobel prizes, the discovery of CP violation in K decays, the discovery of the muon neutrino, and the discovery of the J/psi particle were awarded for work done at the AGS. A fourth, for the suggestion of parity violation, was made for work carried out at AGS during 1956.

- Relativistic Heavy Ion Collider (RHIC): RHIC is a storage ring in which counter rotating beams of heavy ions, injected from the AGS, will collide and produce the density and temperature of nuclear matter characteristic of the early stages of the universe. It will be ready for experiments in 1999.

- High Flux Beam Reactor (HFBR): The HFBR is a 60 Megawatt reactor designed to maximize the flux of neutrons for neutron scattering experiments, mostly in condensed matter. Neutrons are a unique, nondestructive tool for probing magnetic materials, crystal structure of materials containing light elements, vibrational modes in solids, and the interior of solids. There are more than 270 users of the HFBR in areas such as condensed matter physics, biology, chemistry, applied science, and industrial applications.

- National Synchrotron Light Source (NSLS): NSLS is two electron storage rings which provide X Ray, ultraviolet, and infra red beams for research in materials science, biology, chemistry, medical, and industrial applications. There are over 3400 users, including scientists from universities, industry, and other government laboratories.

Other facilities include the Positron Emission Tomograph (PET) which uses positron decays to produce images of the brain, and STEM, a scanning transmission electron microscope which is unique in its capabilities. These facilities are used not only by outside users but also by BNL researchers.

3. Idaho National Engineering Laboratory (INEL), Idaho

INEL includes more than 890 square miles of remote, accessible terrain, well-suited for development, demonstration and operation of complex processes. The Lab's 7,400-member staff represents the largest concentration of technical professionals in the region. INEL is recognized internationally for integration of engineering, applied science and operations to meet critical needs associated with energy supply, environmental management, national security and advanced technology development and demonstration. INEL's core competencies are:

- Systems Integration and Engineering: INEL discerns the future impacts, requirements, and potential problems associated with each of its major programs. The Lab's demonstrated skill in this are has resulted in more than 45 years of safe, environmentally conscious and cost effective operations. INEL has developed and operated 52 unique nuclear reactors, and contributed extensively to the safe applications of this technology in both the commercial power and national security sectors.

- Complex Process Development, Demonstration, and Operation: INEL efficiently move technical ideas from concept to operational status. A wide variety of prototype development and demonstration projects in support of environmental technology applications, renewable and alternative energy systems, advanced transportation concepts, advanced manufacturing methods, and non-proliferation technology applications have been successfully undertaken. Applying this core competency is evidenced by the successful operation of (a) major test reactors, including the Advanced Test Reactor, (b) chemical processing facilities, such as the Idaho Chemical Processing Plant, (c) manufacturing facilities, such as the Specific Manufacturing Capability Facility, and (d) commercial processes, such as automated welding. Capabilities required to design, construct, integrate, and operate such facilities are unique within the DOE complex, because of the breath of applications and the magnitude and complexity of facilities. INEL infrastructure, project management skills, systems integration, and engineering support provide the necessary ingredients for new and expanded missions in this area.

- Environmental Technology Development and Waste Management: INEL has pioneered in developing and providing methods for characterizing, treating and storing radioactive and hazardous waste, including high- and low-level waste treatment technologies. INEL's leadership in environmental technology and waste management result from a unique integration of capabilities including remote handling, biological and chemical processing, instrumentation and sensors, and earth and environmental sciences. INEL's competencies in systems integration and engineering, and in complex process development, have provided the foundation for meeting all environmental-related "records of decision" and supporting milestones on schedule, while maintaining the lowest cost in the laboratory system.

INEL is marked by an emphasis on applied science and engineering to bridge the gap between basic research and practical application, culture oriented toward providing maximum value to customers, proven ability to leverage environmental capability to regional natural resource industries, and unique infrastructure enabling a full range of design, development, demonstration and operations.

In addition, INEL continues to cost effectively leverage limited programmatic resources through a variety of partnership arrangements to facilitate transfer of technology to the private sector.

4. Lawrence Berkeley Laboratory (LBL), California

LBL's dedication to scientific excellence has garnered a host of awards -- including nine Nobel prizes. Its close connection with the University of California at Berkeley permits the lab and its 2,700-member staff to be especially aggressive in educating future scientists and engineers as well as improving the quality of K-12 science education. LBL core competencies include:

- ***Advanced Materials, Synthesis, Characterization and Processing***: Fundamental research here led to the development of detectors based on high-temperature superconducting materials, advances in nuclear magnetic resonance, nanoscale materials for energy applications, basic knowledge of chemical reactions in combustion, and surface-science research.

- ***Advanced Computing, Modeling and Simulation***: Activities include programs in three gigabit network testbeds; developing systems such as digital video analysis; research on economical paths to high-volume, high-speed data storage; and Internet-based multimedia applications for worldwide network-independent teleconferencing.

- ***Advanced Manufacturing and Process Technology***: LBL leads the Automation Technical Area within AMTEX, a partnership with the integrated U.S. textile industry. Other programs involve advanced lithography, and micro-electromechanical systems which apply processing techniques developed for semiconductors to the design of microscopic sensors, actuators, and motors

- ***Biosciences and Biotechnology***: Activities include the rational design of pharmaceuticals; research on coronary artery disease; the biology of breast cancer; advanced imaging techniques like tritium NMR, high-resolution positron emission tomography, and radiopharmaceutical chemistry; transgenic mouse facility for testing atherosclerosis treatments and for on-going clinical hereditary studies; genomic DNA sequencing supported by development of automated instrumentation; lipoprotein and atherosclerosis research program.; and a hematopoiesis program.

- ***Nuclear Science and Technology / High-Energy and Nuclear Physics***: LBL supports research in the nuclear and chemical properties of the heaviest elements; leadership in the STAR experiment at Brookhaven's Relativistic Heavy Ion Collider; participation at Fermilab includes CDF and D0 detector collaborations; originating the technical basis and now partners in the B-Factory at SLAC; astrophysics programs including a search for distant supernovae, direct detection of dark matter, investigations of the cosmic microwave background and the Sudbury Neutrino Observatory. This research is supported and complemented by premier programs in designing and building particle detectors and in many areas of accelerator physics and technology, including design and analysis, superconducting materials and magnets, and beam electrodynamics.

- ***Advanced Energy Technologies & End-Use Applications***: Programs include development of inertial-confinement fusion energy; gas and oil recovery and geothermal resources; energy efficiency; and creation of technologies, processes, and analytical methods in building technology, transportation, utilities, industry, and policy development.

- ***Environmental Science & Remediation Technology***: LBL research is aimed at understanding the formation, transport, transformation, mitigation, and ecological effects of pollutants on the environment including research in fractured porous systems such as soil and rock; advanced site-characterization, remediation, and separation methods for use at contaminated sites or sites with special geologic interest; subsurface barrier technology; methods for removing and recovering toxic metals from aqueous waste streams; hazards of the indoor environment including radon and other indoor air pollutants; research on climate change; and fundamental actinide chemistry and processes that impact environmental remediation and restoration.

Among LBL national research facilities are:
- The Advanced Light Source,
- The 88-Inch Cyclotron,
- The National Center for Electron Microscopy, and
- The National Tritium Labeling Facility.

5. Lawrence Livermore National Laboratory (LLNL), California

LLNL and its 7,900-member staff focus their efforts on global security, global ecology, and bioscience. LLNL offers a demonstrated ability to apply science and technology effectively on a large scale, thanks to a broad culture of diverse disciplines and well-developed links to industry and the university R&D communities. Core competencies and characteristics include:

- ***Nuclear Science***: LLNL is one of two nuclear weapon design laboratories and has applied this knowledge to fusion and nuclear energy, atomic (x ray) and nuclear physics, and astrophysics. The Lab serves as an expert resource on international nuclear weapon and nuclear materials issues.

- ***Computation***: LLNL operates several supercomputer centers, including the DOE's national supercomputer center and network, and the national information storage laboratory. The Lab deployed the first machines of many generations of new computers; developed scientific computation, operating, and system control languages; pioneered time sharing and network management; and is engaged in the national effort to develop massively parallel computational capabilities.

- ***Lasers***: The LLNL world-leading laser program is very directed, developing lasers which have specific applications -- adding to the national capability in glass lasers, metal vapor and dye lasers, and now solid state diode lasers. The Lab has adapted these technologies to astronomy, satellite systems, biology, and advanced manufacturing.

- ***Instrumentation and Sensors***: Instrumentation and sensor capabilities derive initially from the critical and demanding needs of weapons testing. The requirements for laser, biology, environment, and energy systems and for precision engineering have further evolved this capability.

- ***Bioscience***: LLNL, one of the three DOE centers for the study of the human genome, has mapped most of chromosome 19 with sequenced, cloned DNA fragments and has helped locate 170 genes, 3 repair genes, and many biological functions and pathologies associated with this chromosome. In addition, Livermore is developing bioscience applications for healthcare, environmental cleanup, and energy conversion.

- ***Materials and Processing***: LLNL developed materials that are the lightest known solids, best thermal and electrical insulators, and with the highest toughness-to-weight ratio; fabricated materials an atomic layer at a time; built microstructures and micromachines; and, in collaboration with Russian scientists, increased the growth rate of optics crystals by 100 times. The Lab developed and uranium laser isotope separation (AVLIS); this is the nation's largest and most complex process technology transfer.

Among unique facilities at LLNL are the National Energy Research Supercomputer Center (NERSC); the world's most powerful laser (Nova); the laser isotope separation demonstration facility (AVLIS); the best instrumented hydrodynamics test facility (FXR); the country's most advanced energetic materials research facility (HEAF); the most precise diamond turning machine (LODTM) which cut metal mirrors for the Keck telescope; the electron beam ion trap (EBIT) capable of studying atomic structure of any element at extremely deep ionization levels; the nation's most productive and diverse center for accelerator mass spectrometry (CAMS); the nation's atmospheric release advisory capability (ARAC) which analyzed Chernobyl in real time; the national center for global climate model comparison; the genome research center; and environmental technology demonstration facilities for dynamic underground stripping, for groundwater cleanup, and for mixed waste treatment.

6. National Renewable Energy Laboratory (NREL), Colorado

NREL has a compelling mission: "[to lead] the nation toward a sustainable energy future by developing renewable energy technologies, improving energy efficiency, advancing related science and engineering, and facilitating commercialization." Further, NREL is the only DOE Laboratory solely dedicated to developing renewable energy technologies (RETs) and related energy efficiency technologies, which includes helping to build a viable industry. NREL's current technical staff of more than 500 represents the largest concentration of expertise focused on renewable energy technologies in the world. This highly trained staff is further augmented by unique experimental and user facilities.

To help meet its challenging mission, NREL carries out its activities using a process called vertically integrated research and development (R&D) and partnership development by working closely and in parallel with industry, university, and national lab partners, as well as other stakeholders, to evolve and develop technology of commercial interest through all its stages -- from basic research through applied research, engineering, product development, manufacturing support and, finally, in a supporting role, commercialization. These efforts rely heavily on four core competencies:

- Advanced Materials and Prototype Component Development

- Development and Characterization of Renewable Energy, Energy Efficiency, and Waste Conversion Processes

- Systems and Process Engineering and Integration for Renewable Energy and Energy Efficiency

- Establishing Partnerships for Market and Technology Development for Renewables and Energy Efficiency

In addition, as part of this vertically integrated process NREL, guided by a number of review and advisory boards made up of members of industry, academia, users, and institutions:

- Serves as the focal point for planning and implementing the federal RET R&D program in industry and universities;

- Technically evaluates and plans projects for the deployment of RETs and carries out DOE-assigned program management;

- Serves as the "corporate memory" to assure that lessons learned are applied to the next generation of RET projects;

- Develops collaborative relationships with research institutes abroad, leading to a better understanding of, and familiarity with, U.S. manufacturers and products;

- Transfers RET and related technology from the Laboratory to U.S. industry; and

- Provides scientific and technical information on a wide range of RETs to other agencies and industry.

7. Los Alamos National Laboratory (LANL), New Mexico

LANL is a world class laboratory which attracts and retains a high caliber staff of 7,600. The Lab also continually draws internationally renowned scientists, both foreign and domestic, from universities, industry, and government-funded laboratories. LANL competencies and distinguishing characteristics include:

- ***Nuclear Weapons and Materials***: LANL has exceptional broad capabilities, with several unique facilities including the Plutonium Facility, the Chemistry and Metallurgy Research Building, and the Critical Experiments Facility. They permit research, development, and demonstration of process technology, fabrication, safety and criticality studies, and waste treatment. Explosive and energetic materials capabilities extend from synthesis and characterization to pilot scale production to machining and fabrication to engineering and testing. Flash x ray capabilities allow imaging of dynamic events.

- ***Scientific Computing***: LANL has one of the two largest capabilities in this area, a capacity that allows the Lab a leadership role in addressing some of the nations grand challenges. An example is development of the parallel ocean model, a program that received the Computerworld Smithsonian Award for technical excellence in the science category. LANL is the site of one of two DOE High Performance Computing Centers, and supports the Computational Testbed for Industry, as well as the Los Alamos Neutron Scattering Center (LANSCE), a pulsed neutron source with a large and vigorous user community. Research activities cover the spectrum from materials studies to structural biology, and LANSCE is expected to play a key role in the proposed nuclear weapons stewardship initiative.

- ***Sensors and Diagnostics***: LANL is a leader in developing techniques for capturing transient signals under extremes of temperature and pressure. Sensors and diagnostics have been deployed in environments from subsurface to oceans to space. These capabilities play an important role in the growing area of non and counterproliferation, a national program in which LANL is a leader.

- ***Biology***: LANL has one of three DOE Centers for Human Genome Studies, which has earned international stature deriving largely from the interface that has been achieved between researchers in biology and those from the physical sciences, computation, and the engineering sciences.

8. Oak Ridge National Laboratory (ORNL), Tennessee

ORNL is a world-class, wide-ranging scientific R&D institution thanks to its technical accomplishments, outstanding staff, extensive facilities, diverse programs, and broad collaborations. The 5,100-member ORNL staff represents an unusually wide range of disciplines, and includes 1,500 scientists and engineers. ORNL hosts more than 4,000 guest scientists per year, representing 250 companies and universities, as well as over 20,000 students and several hundred teachers. ORNL core competencies include:

- ***Energy production and end-use technologies***: ORNL is one of the world's premier centers for R&D on energy efficiency and supply technologies and on the economic, social and environmental consequences of energy systems and processes. The Buildings Technology Center has the nation's most versatile capability for testing and analysis of building equipment and envelope systems.

- ***Biological and environmental science and technology***: ORNL offers unique capabilities for investigating pathways, fate and effects of anthropogenic materials in the environment, and has the only formal Protein Engineering Program within DOE. The Mammalian Genetics Facility is a unique national resource for genetics research.

- ***Advanced materials synthesis, processing, and characterization***: An extremely broad range of materials R&D is conducted, with particular excellence in high temperature ceramics and composites, metals and intermetallic alloys, superconductors, semiconductors, optical materials, and surfaces and thin films. The High Temperature Materials Laboratory is a unique and popular user facility for materials research.

- ***Neutron-based science and technology***: This competency includes the design and operation of research reactors, accelerators, and hot cells; neutron scattering; isotope production and research, materials irradiation and testing, neutron activation analysis, radiation chemistry, health physics and radiation effects, and nuclear medicine. Unique facilities include the High Flux Isotope Reactor (HFIR) and Radiochemical Engineering Development Center (REDC).

Supporting these core competencies are facilities and capabilities unavailable elsewhere, such as the:

- Holifield Radioactive Ion Beam Facility,
- Center for Computation Science (one of two such DOE centers).

9. Pacific Northwest Laboratory (PNL), Washington State

PNL and its 4,000-member staff are located on the Hanford Site, a factor which heavily influences the Lab's technical composition. PNL entered the DOE Multiprogram Laboratory System in 1986, well-positioned to shift focus from support of defense production to environmental issues and cleanup. DOE and PNL management committed to establish a world-class fundamental science base in bioscience, chemistry, chemical physics and process science, directly related to the nation's environmental problems. PNL possesses three core competencies:

- ***Integrated Environmental Research***: Key technical capabilities are in the fields of ecological sciences, hydrology, geochemistry/geophysics, atmospheric chemistry, chemistry and chemical physics, bioscience, economics and policy analysis, and computational sciences. PNL offers a proven ability to form large cross-disciplinary teams to address large-scale environmental issues. PNL leads the OHER Subsurface Science Program, the Atmospheric Radiation Measurement Program of the DOE Global Environmental Change Research Program, and is constructing the Environmental and Molecular Science Laboratory (EMSL) as a national collaborative research facility.

- ***Process Science and Engineering***: As the science and technology integrator at Hanford, PNL leads in Hanford's Tank Waste Remediation System and the National Tanks Program -- bringing to bear long-standing process skills related to defense-waste storage, treatment and packaging technology. This competency is highly coupled with the integrated environmental research competency because remediation and storage performance criteria must be based on scientifically sound standards governing environmental and biological risk. Technical skills are focused on chemical and physical characterization, tank safety, separations science, waste form development and performance, and systems engineering.

- ***Energy Systems Development***: Energy Systems Development is underpinned both by technology, and economic and policy analysis expertise. Historically, PNL has played key research roles in regional power issues, energy policy analysis, and more recently in technical areas of residential and industrial power usage, and power transmission and distribution systems. Distinguishing characteristics are exemplified by excellence in scientifically based economic models to address energy, agricultural, and ecological policy issues relative to global and regional environmental change.

10. Sandia National Laboratories (SNL), New Mexico

Sandia is a systems engineering laboratory. It was created in 1949 to team industrial management and government experience in the design of deployable nuclear weapons as well as the surety and reliability of the nuclear weapons stockpile.

Sandia is located in Albuquerque, New Mexico, and in Livermore, California, with the New Mexico site being the larger facility. Sandia operates a wide variety of technical and user facilities, the collection of which constitutes one of the world's premier research, development, and testing complexes. The staff of 8,500 employees performs work for DOE national security programs (about 50% of laboratory effort), DOE energy and environmental programs (about 25%) and work for other federal agencies (25%). Ninety percent of the work for other federal agencies is for DoD.

Sandia's core competencies include the following research foundations and integrated capabilities:

Research Foundations:

- ***Engineered Processes and Material***: The synthesis, characterization, and processing of metallic, ceramic, organic, and composite materials; advanced materials and processes tailored for specific applications.

- ***Computational and Information Sciences***: The development of advanced computing networks, computational methods for emerging computer technologies, mathematical techniques for information surety, and computer-based techniques for intelligent machines.

- ***Microelectronics and Photonics***: Materials growth and development, device design, fabrication technologies for silicon and compound semiconductor devices, and design of processes and equipment for the manufacture of integrated circuits.

- ***Engineering Sciences***: Fluid and thermal sciences, solid and structural mechanics, radiation transport, aerospace sciences, geoscience, combustion science, and the development of interdisciplinary capabilities.

Integrated Capabilities:

- ***Advanced Manufacturing Technology***: Leadership in advanced manufacturing to make continuing, critical, and valuable contributions to national security, energy security, environmental stewardship, and economic competitiveness.

- ***Electronics Technology***: Leadership in electronics technology for defense and industry.

- ***Advanced Information Technology***: Technology and systems for nuclear weapon programs, related mission assignments, other strategic thrusts, and national information initiatives.

- ***Pulsed Power Technology***: High-power x-ray and gamma ray sources for a variety of applications, including nuclear weapon survivability testing, light-ion beam inertial confinement fusion, materials processing, waste and product sterilization.